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STARS WHOSE SPECTRA CONTAIN BOTH BRIGHT AND DARK HYDROGEN LINES.

By W. W. CAMPBELL.

IN the progress of the Henry Draper Memorial the astronomers of Harvard College Observatory have discovered an almost incredibly long list of objects having bright-line spectra. These discoveries include

Wolf-Rayet stars,
Gaseous nebulae,
New star (in Norma),
Variable stars (from bright lines in their spectra),
"Bright $H\beta$" stars.

It is impossible to overestimate the value of these additions to the previously meager number of bright-line objects. Discoveries of objects of the last-named kind have been announced in the briefest possible manner as "Bright $H\beta$" stars, and have as yet received little attention from spectroscopists. I have no hesitation in venturing the opinion that they will prove to be the most valuable objects on the above list.

My 1893–4 observations of the Wolf-Rayet star γ Argus showed that the $H\alpha$ line is quite bright in that star, whereas $H\gamma$, $H\delta$, $H\epsilon$ are dark. Of several negatives of the $H\beta$ region, two

exhibit a very faint bright band with a partially dark fine line in its center at λ 4861. The photographs show clearly that the dark $H\epsilon$ is stronger than $H\delta$, and that $H\delta$ is stronger than $H\gamma$.[1] "The photographic results obtained by Pickering at the Peruvian station of the Harvard College Observatory . . . . confirm the Lick observations as regards the violet lines, and show the ultra-violet lines $H\zeta$ to $H\iota$ to be also dark. . . . . Of course the plates do not extend to $H\alpha$."[2]

The hydrogen lines in the Wolf-Rayet star *B.D.*+43°3571 appear to have the same characteristics as those in γ Argus.[3]

At about the same time, I found that in η Tauri (Alcyone) the $H\alpha$ line is bright, with a narrow dark line on its more refrangible side. There is possibly a very narrow dark line on its less refrangible side. In February 1895, I asked Professor Schaeberle to observe the $H\alpha$ region of this spectrum. Without knowing the peculiarity of this star, he described the $H\alpha$ region exactly as I have above. It is well known that $H\beta$, $H\gamma$, $H\delta$, etc., in η Tauri are dark.

After observing γ Argus and η Tauri, I examined several of the Harvard "Bright $H\beta$" stars to see if $H\alpha$ is also bright, and found in nearly every spectrum observed that $H\alpha$ is very bright and easy. Photographs of a few of the spectra show most interesting peculiarities, which, in connection with the visual observations of the $H\alpha$ line, convinced me of the great importance of these stars. To illustrate, let us briefly consider the star φ Persei. $H\alpha$ is very bright, $H\beta$ is fairly bright, the photographs show $H\gamma$ and $H\delta$ to consist each of two narrow bright lines, faint, about four tenth-meters apart, $H\gamma$ being stronger than $H\delta$. The intensity of the hydrogen lines decreases rapidly as we approach the violet end of the spectrum. The photographs show many other interesting features, aside from the hydrogen lines.

Again, my photographs show many striking facts concerning γ Cassiopeiae. The bright hydrogen lines decrease in intensity

[1] *A. and A.*, 1894, p. 457.

[2] Frost's *Astronomical Spectroscopy*, p. 277.

[3] *A. and A.*, 1894, p. 466.

very rapidly as we go toward the violet, and are situated within broad dark hydrogen lines. A number of partially dark lines are shown at other points in the spectrum, thus confirming Professor Keeler's visual and photographic observations of dark lines in this spectrum.

The chromatic aberration of the 36-inch lenses made it impossible to study these spectra beyond $H\delta$ or $H\epsilon$. In order to gain an idea of their spectra in the ultra-violet, I asked Professor Pickering to photograph the spectrum of γ Cassiopeiae for me. In response, I received beautiful copies of his earlier photographs of γ Cassiopeiae and μ Centauri. They show conclusively the presence of a great many dark lines in both spectra; also, that the dark hydrogen lines, as they diminish in wave-length, increase in intensity, while the corresponding bright hydrogen lines which are superposed on them, decrease. These photographs contain a vast amount of information which unfortunately has not been published.

I have in the past year examined visually all the available stars of the "bright $H\beta$" type, and have secured photographs of limited regions in the spectra of several of them. While the work was in progress, the Observatory was so fortunate as to receive as a gift the 36-inch Crossley reflector. The advantages of the reflector over the 36-inch refractor in this work are so great that I shall regard the photographs now on hand as purely provisional,—hoping to undertake anew the investigation of these stars as soon as the Crossley reflector is mounted, and provided with a suitable spectrograph. In this general note I shall only record my observations of the $H\alpha$ and D_3 lines, reserving the more detailed data for a future paper.

The following list of stars contains possibly all those, up to January 1895, which should be especially investigated with reference to their bright and dark hydrogen lines. The bright lines noted in the last column were observed at Mt. Hamilton, except in the cases accredited to other observers. Unless otherwise specified, $H\beta$ (and possibly one or more succeeding hydrogen lines) has been observed to be bright by the Harvard College observers.

Star	Mag.	α 1900.0	δ 1900.0	Bright Lines Observed
γ Cassiopeiae	2.3	$0^h\ 50^m.7$	+ 60° 11′	Bright *Hα*, etc., well known
φ Persei	4.2	1 37 .4	+ 50 11	*Hα*, *Hβ* [1]
B.D. + 65°340	4.5	3 11 .2	+ 65 17	*Hα*
ψ Persei	4.2	3 29 .4	+ 47 52	*Hα*
η Tauri	3.0	3 41 .5	+ 23 48	*Hα*. Other *H* lines dark
Pleione	6.2	3 43 .2	+ 23 50	*Hα* [2]
B.D. + 30°591	6.5	3 49 .1	+ 30 45	*Hα*, D_3 [3]
A.G.C. 5014	5.7	4 24 .5	— 13 16	*Hα*
A.G.C. 7191	5.8	5 59 .4	— 6 42	*Hα*
A.G.C. 7883	4.2	6 24 .0	— 6 58	*Hα* [4]
A.G.C. 7886	8	6 24 .0	— 6 58	*Hα* [4]
A.G.C. 8518	4.0	6 46 .1	— 32 24	*Hα*
B.D. −10°1774	7.2	6 52 .5	— 10 42	See footnote [5]
A.G.C. 9181	5.4	7 10 .2	— 26 11	*Hα*
A.G.C. 9198	4.2	7 10 .8	— 26 36	*Hα*
A.G.C. 9326	5.3	7 14 .8	— 36 33	*Hα*
A.G.C. 10963	5.3	8 9 .7	— 35 36	*Hα*
A.G.C. 14392	3.6	10 28 .5	— 61 10	Star not visible at L. O.
δ Centauri	2.8	12 3 .2	— 50 10	*Hα*
κ Draconis	3.8	12 29 .2	+ 70 20	*Hα*
A.G.C. 17717	6.6	12 56 .3	— 70 56	Star not visible at L. O.
μ Centauri	3.4	13 43 .6	— 41 59	*Hα*
A.G.C. 18859	6.6	13 47 .7	— 46 38	Did not see bright *Hα*
A.G.C. 19737	2.5	14 29 .2	— 41 43	*Hα*
χ Ophiuchi	4.6	16 21 .2	— 18 14	*Hα*
A.G.C. 24550	6.1	17 57 .7	— 24 22	Did not see bright *Hα*
v Sagittarii	4.7	19 16 .0	— 16 9	*Hα*
P Cygni	4.9	20 14 .1	+ 37 43	Bright lines well known [6]
v Cygni	4.4	21 13 .8	+ 34 29	*Hα*
B.D. + 11°4673	7.7	21 46 .2	+ 12 9	*Hα*
B.D. + 61°2233	7.0	21 57 .6	+ 62 0	Did not see bright *Hα*
π Aquarii	4.6	22 20 .2	+ 0 52	*Hα*

[1] Bright *Hβ* observed by Espin, *A. N.* 2963.

[2] Bright *Hα* observed by Keeler, *A. and A.*, No. 114, p. 352.

[3] Bright D_3 is pretty faint. Pickering writes in a private letter that there is a trace of bright λ 4471.

[4] *A.G.C.* 7883 and 7886 are the preceding and following stars in the triple star 11 Monocerotis. The intermediate star does not show a bright *Hα*. I understand that on the Harvard plates the three superposed spectra show a "bright *Hβ*."

[5] Professor Pickering has recently informed me that the star *B.D.* −10°1786, originally announced as a "bright *Hβ*," should be changed to *B.D.* −10°1774. I have therefore not yet examined −10°1774.

[6] Observations by Keeler. *A. and A.*, **12**, 361.

It is not surprising that bright $H\alpha$ was not seen in the stars *A.G.C.* 18859, *A.G.C.* 24550, *B.D.* $+61^{\circ}2233$, since those stars are rather faint, and Professor Pickering writes that in them the $H\beta$ line is weak.

The above list contains thirty-two stars in which one or more of the hydrogen lines of greater wave-length are bright, in many of which — possibly all of them — the bright hydrogen lines decrease in intensity as we go towards the violet, and in many of which the hydrogen lines of shorter wave-length are dark. The list must be considered as provisional, — in the nature of a working list. Possibly some of the stars should be omitted, and possibly others — notably some of the variable stars — should be included.

These stars naturally fall under Professor Vogel's Class Ic, though D_3 is not present in many of them. They must be considered as belonging to a very early stage in sidereal evolution. Therein lies one element of their great importance; but their chief significance lies in the fact that they represent *many steps* in the evolutionary process in the neighborhood of one of the most important points in that process. η Tauri has always been classed as Ia; but the discovery of one faint bright line, $H\alpha$, in its spectrum places it in Class Ic. It is therefore very near the boundary between Classes Ic and Ia. Some of these stars may contain only two bright hydrogen lines, $H\alpha$ and $H\beta$. Others may contain three or more. γ Cassiopeiae certainly contains half a dozen bright hydrogen lines, and long exposures would probably show traces of a few other bright lines in the ultra-violet where now none are shown by exposures of reasonable length. It is possible that some stars contain bright hydrogen lines throughout the whole of the available spectrum. It is also possible that long exposures would bring out faint bright lines within the dark $H\beta$, $H\gamma$, etc., lines of η Tauri. However, the following points I consider to be firmly established:

(*a*) Some stars contain both bright and dark hydrogen lines.

(*b*) The bright lines in such stars are those of greater wave-length, the dark lines are those of shorter wave-length.

(*c*) The intensities of the bright lines decrease as we approach the violet.

(*d*) The intensities of the dark lines increase as we approach the violet.

The explanation of these facts is not evident. At the World's Fair Congress of Astronomy held in Chicago in 1893 I believe Professor Frost suggested a partial explanation of the bright $H\alpha$ and dark $H\gamma$, $H\delta$, $H\epsilon$, in γ Argus, on the basis that the extensive stellar atmosphere would absorb the rays of shorter wave-length proceeding from the inner (photospheric) portions of the star more powerfully than it would the waves of greater wave-length. The reasoning is this: Measurements with the spectral photometer have shown that the *general* absorption of the Sun's atmosphere is about 1.7 times as great for the violet as for the red rays; the case is doubtless similar for many of the stars, particularly for those having extensive atmospheres; if the same conditions applied to the *selective* as to the *general* absorption, at least a part of the contrast between bright $H\alpha$ and dark $H\gamma$ would be accounted for. In view of the dubiousness of the assumption that similar conditions hold for selective and general absorption, Professor Frost has not published the suggestion. It seems to me, however, that his suggestion is useful, and really points in the direction from which the true explanation will come.

Professor Scheiner says in *Die Spectralanalyse der Gestirne:*[1] "There can be nothing more natural than to assume that the stars of Class Ic, which have far more powerful atmospheres than those of Class Ia, are in a preliminary state from which they will gradually pass over into Class Ia." I heartily subscribe to that opinion. It follows logically that some at least of the stars of Class Ia were, at an earlier age, in Class Ic. How does a star of Class Ic pass over into Class Ia? If a star of Class Ic contains *one* bright hydrogen line, must *all* its hydrogen lines be bright? If a star contains *one* dark hydrogen line, must *all* its hydrogen lines be dark? If a bright-line star passes over into a dark-line star, do all the hydrogen lines change their character

[1] See Frost's translation, p. 250, last paragraph.

at the same instant? In general, the hydrogen lines probably change in the same *direction*, simultaneously; but do they change from bright lines to dark lines, or from bright lines to continuous spectrum and thence to dark lines, at the same instant? That would seem to me to be improbable. The character of a spectrum is the resultant of radiation and absorption phenomena. Stars of Class Ic seem to have atmospheres enormously extensive and very hot. Cooling and contraction cause progressive changes in their spectra. If we start with a star whose atmosphere is exceedingly extensive, and very hot throughout, our knowledge of the effects of decreasing temperatures in the outer portions of that atmosphere would lead us to expect that certain radiation phenomena should decrease, while certain absorption phenomena should increase. The conditions existing on our Sun are inadequate to explain the phenomena observed in the above stars. However, if the conditions existing on our Sun are sufficient to account for *any fractional part* of the contrast existing between the hydrogen lines in these stars, the difficulty is largely removed; for we must remember that our Sun is old, of Class IIa, whereas stars of Class Ic may safely be assigned exceedingly extensive atmospheres.

The points contained in this paper bear upon Professor Scheiner's notes (7), (8), (9) in the preface to Frost's *Astronomical Spectroscopy*.

MT. HAMILTON,
June 28, 1894.

THE ARC-SPECTRA OF THE ELEMENTS. III.

PLATINUM AND OSMIUM.

By Henry A. Rowland and Robert R. Tatnall.

Since the appearance of the second part of the present paper in Vol. I., No. 2, of The Astrophysical Journal, the ultra-violet spectra of some of the metals of the platinum group have been studied, mostly in the region between λ 3000 and λ 4600. The measurements have all been made upon plates containing second-order spectra.

Owing to the extreme difficulty experienced by the chemist in separating the members of this group from one another, the spectra upon our plates are very impure, and those of rhodium, ruthenium, and palladium, in particular, are much confused, so that the spectrum of either of these metals contains most of the principal lines of the other two. While this fact has very greatly increased the difficulty and uncertainty of identifying the lines, it has also added much to the accuracy of the measurements, since many of the heavier lines have been measured upon several different plates. The wave-lengths given in the following tables are the means of all measurements.

The heavier lines have been examined as to the probability of their occurrence in the solar spectrum, and the investigation has confirmed the existence of rhodium and palladium in the Sun. Ruthenium is doubtful, and it is most probable that there are no solar lines of appreciable intensity belonging to platinum or osmium, in this region of the spectrum. The most intense lines in the arc-spectra of rhodium and palladium correspond to extremely weak solar lines, and for this reason it seems best to defer a careful identification of these until after the completion of Rowland's Table of Solar Spectrum Wave-lengths, since a direct comparison of wave-length readings with those to be found in that table will give more certain results than can be

obtained by the use of Rowland's map, or by comparison of plates.

Beryllium.—Owing to an error in the preparation of the table of wave-lengths of beryllium lines (ASTROPHYSICAL JOURNAL, Vol. I., p. 16), the wave-lengths there given should read as follows:

2175.102	2986.177
2348.698	2986.547
2350.855	3130.556
2494.532	3131.200
2494.960	3321.218
2650.414	3321.486
2651.042	3367.720
2898.352	4572.869

PLATINUM.

(*W.-l. 3000 to 4600.*)

Wave-length	Intensity and Character	Wave-length	Intensity and Character	Wave-length	Intensity and Character	Wave-length	Intensity and Character
2998.079	15 r[1]	3252.103	4	3476.900	3	3681.229	2
3002.388	5 s	3256.038	5	3483.561	6	3683.123	3
3017.983	2 s	3259.859	3	3485.411	7	3687.554	3
3036.562	4	3261.819	2	3491.141	2 n	3700.059	5
3042.745	5 r	3268.570	3	3498.308	1	3706.667	7
3059.749	3	3282.097	3	3505.835	1 n	3717.982	2
3064.824	15 r	3283.332	2	3514.887	3	3818.827	4
3072.042	4	3283.436	2	3528.691	3	3898.886	3
3100.136	5 s	3290.370	6	3587.555	3	3900.874	4
3101.070	3	3301.996	12	3611.060	3	3911.050	2
3139.505	7	3315.182	5	3621.812	2	3923.106	2
3156.683	6	3323.921	4	3627.226	1	3925.486	4
3200.830	6	3344.037	3	3628.272	10 s	3948.539	5
3204.161	8	3367.135	4	3629.017	5	3959.170	2
3212.493	1	3408.277		3638.944	8 s	3966.504	12
3227.290	1	3426.880		3643.313	8	3996.722	3
3230.406	4	3428.110		3659.564	2	4012.016	2
3233.541	4	3432.023		3663.242	3	4047.796	4
3240.323	3	3454.285	2	3672.142	10 s	4054.925	2
3250.475	3	3464.080	1 n	3674.191	9 s	4066.094	2

[1] In all the tables,
r indicates *reversed*,
s indicates *sharp*,
n indicates *hazy* or *nebulous*.

PLATINUM.—*Continued.*

Wave-length	Intensity and Character	Wave-length	Intensity and Character	Wave-length	Intensity and Character	Wave-length	Intensity and Character
4069.850	2	4192.589	5	4340.002	2	4391.996	10
4081.627	2	4205.015	4	4346.983	7	4442.723	20 s
4092.421	2	4227.523	4	4358.025	4	4445.713	5
4095.030	4	4252.229	3	4370.483	10	4498.930	4
4118.838	10 s	4288.217	2	4379.184	8	4552.594	12
4132.544	3	4327.230	10	4382.243	3	4554.828	12
4164.722	6						

OSMIUM.

(*W.-l. 3000 to 4600.*)

Wave-length	Intensity and Character	Wave-length	Intensity and Character	Wave-length	Intensity and Character	Wave-length	Intensity and Character
3018.155	5	3930.138	5	4053.407	2	4251.331	1
3041.023	3	3931.660	3	4055.641	2	4252.690	1
3058.766	5	3938.739	6	4066.464	2	4260.993	25
3077.841	3	3939.708	4	4066.848	15	4264.903	3
3156.384	5	3949.921	4	4071.008	5	4269.521	2
3232.195	3	3952.911	3	4071.162	3	4269.767	4
3268.078	5	3960.653	3	4071.716	5	4270.945	2
3301.708	8	3961.163	5	4073.763	5	4275.064	2
3336.301	3	3963.777	10	4074.834	5	4277.302	3
3370.730	3	3965.112	3	4088.593	2	4281.529	1
3402.001	2	3969.835	5	4090.922	3	4286.056	4
3402.654	1	3975.598	3	4091.977	8	4294.113	10
3445.699	2	3977.391	10	4097.004	3	4296.383	3
3449.346	3	3979.521	2	4097.090	3	4297.538	1
3504.815	3	3988.343	4	4098.264	2	4299.856	1
3598.264	3	3988.783	2	4100.446	4	4305.440	1
3640.484	3	3991.640	2	4112.185	12	4309.041	2
3654.639	2	3995.096	2	4124.762	4	4311.560	10
3657.053	3	3996.972	2	4129.124	8	4317.743	1
3671.040	3	3999.103	2	4135.945	20	4319.502	2
3790.244	3	4003.652	5	4138.013	3	4326.416	5
3794.054	2	4004.193	5	4152.455	10	4328.840	9
3876.971	3	4005.327	7	4158.948	2	4338.919	3
3895.023	2	4015.211	2	4172.710	4	4342.678	1
3895.305	3	4018.430	5	4173.386	8	4351.691	3
3900.527	4	4033.095	2	4175.781	5	4354.626	2
3901.843	5	4035.250	2	4190.052	4	4358.153	2
3918.888	2	4036.634	2	4201.528	3	4358.304	2
3919.107	2	4038.017	3	4212.007	6	4365.837	8
3925.244	3	4038.782	2	4218.991	1	4370.824	4
3926.916	3	4042.073	6	4226.675	3	4377.068	1
3928.554	3	4048.197	4	4233.613	4	4391.242	2
3928.681	3	4051.580	2	4241.679	1	4395.042	9

OSMIUM.—*Continued.*

Wave-length	Intensity and Character	Wave-length	Intensity and Character	Wave-length	Intensity and Character	Wave-length	Intensity and Character
4397.427	3	4437.257	2	4466.121	1	4548.827	2
4400.747	2	4439.810	2	4479.976	2	4550.571	4
4402.904	4	4445.850	1	4484.930	3	4551.463	3
4404.378	2	4447.520	5	4488.766	2	4616.944	1
4420.633	20	4459.658	1	4525.035	1		
4432.582	3	4459.781	2	4529.842	1		
4436.488	5	4462.470	1	4540.087	1		

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PRELIMINARY TABLE OF SOLAR SPECTRUM WAVE-LENGTHS. VIII.

By HENRY A. ROWLAND.

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
5148.410	Fe	3	5157.376		000
5148.627		0000	5157.783	-,C	000
5148.851		000	5157.915	C,-	000
5149.013		000	5158.152		00
5149.267	C,-	000	5158.701	C	000
5149.392		000	5158.832	C	0000
5149.512		0000	5159.026		0000 N
5149.685		0000 N	5159.231 s	Fe	2
5149.964		000	5159.452		0000
5150.363		00	5159.634	C,-	000
5150.525		0000	5159.776	C	0000
5150.736	-,C	000	5159.946		0000
5150.842	C?	0000	5160.138		000
5151.020 s	Fe	4	5160.419	C,-	00 N
5151.112	Mn	000	5160.554		0000
5151.344		0000 N	5161.006		0000 N
5151.628		0000 N	5161.194	C,-	000
5152.087	Fe	3	5161.353	C,-	000
5152.361	Ti	0	5161.849	C	0000
5152.700		0000	5161.910	C,-	000
5153.129	-C?	000	5162.153	C?	0000
5153.337	C	0000	5162.449 s	Fe, C	5
5153.414	Fe	1	5162.690	C	0000
5153.584		00	5162.902		0000
5153.687		00	5163.074	C,-	000
5153.848		000	5163.200	C,-	000
5153.985		0000 Nd?	5163.327		0000
5154.244 s	Ti-Co	2	5163.585	C,-	000
5154.505	C	0000	5163.756	C,-	000
5154.579		000	5164.007		0000
5154.913		0000	5164.172	C	0000
5155.028		0000	5164.404	C,-	000
5155.303	Ni	1	5164.562		0000
5155.694	C,-	000	5164.724	Fe?	1
5155.935 s	Ni	2	5164.855	C	0000
5156.239		000	5164.950	C	0000
5156.530		000	5165.080	C,-	000
5156.728	C	0000	5165.209	C	0000
5156.823	C,-	00 N	5165.297	C	0000
5157.163		0000	5165.416[1]	C	0000

[1] Head of carbon band.

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
5165.588 s	Fe	2	5180.747		000
5165.746		0000	5181.041		0000
5166.133		0000	5181.334		000
5166.454	Cr-Fe	3	5181.498		00
5167.497 s	Mg	15	5181.719		0000 N
b_4 5167.678 s	Fe	5	5182.010		000
5167.885		00	5182.123		0000
5168.123		0000	5182.518		0000
5168.360		000 Nd?	5182.761		0000
5168.832	Ni	1	5182.907		000
5169.069 s	Fe	3	b_1 5183.791 s	Mg	30
b_3 5169.220 s	Fe	4	5184.364		000
5169.469		00	5184.445	Fe	2
5169.664		0000	5184.738	Fe, Ni, Cr	1
5169.871		0000	5184.998		0000
5170.271		0000	5185.201		0000
5170.655		0000	5186.073	Ti	2
5170.767		000	5186.274		0000
5170.937	Fe	0	5186.497	Fe	000 N
5171.192		0000	5186.718		000
5171.778 s	Fe	6	5187.432		0000
5172.386		00	5187.620		000
b_2 5172.856 s	Mg	20	5188.004		0000
5173.499		0000	5188.079	Fe	1
5173.652		000	5188.227		0000
5173.917 s	Ti	2	5188.409		0000
5174.077		0000	5188.571		0000
5174.203		000	5188.863 s	Ti	2
5174.595		000 N	5189.018 s	Ca	3
5175.099		000	5189.300		000
5175.423		000	5189.503		0000
5175.575		000	5189.744		000
5175.923		000 Nd?	5189.948		000
5176.191	Co	000	5191.244		000
5176 305		000	5191.629	Fe	4
5176.735	Ni	1	5191.768		000
5176.954	V	000	5191.911		0000
5177.179		0000 N	5192.033		0000
5177.410	Fe	0	5192.155	Cr	00
5177.577	Co	00	5192.523	Fe	5
5177.784		0000	5192.659		000
5177.979		0000	5192.785		000
5178.156		0000	5192.924		0000 N
5178.644		000	5193.139 s	Ti	2
5178.970		00	5193.339		0000
5179.293		000	5193.500		0000
5179.695		0000	5193.669	Cr	000
5179.958		000	5194.027		0000
5180.233	Fe	1	5194.216	Ti	000
5180.572		000	5195.113	Fe	4

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
5195.647	Fe	2	5210.555 s	Ti	3
5196.227	Fe	1	5211.015		000
5196.434		0000 N	5211.106		0000
5196.613	Cr	0	5211.367		000
5196.741	Mn	00	5211.700	Fe	00
5197.332	Ni, Mn	00	5211.976		0000
5197.540		0000 N	5212.398		000 N
5197.743		2	5212.503		0000
5197.954		0000	5212.859		000 Nd?
5198.108		0	5213.155		0000
5198.512		0000	5213.515		000
5198.888 s	Fe	3	5213.977		000
5199.033		0000	5214.286	Cr	00
5199.766		000	5214.781		00
5199.879		000	5215.353 s	Fe	3
5200.355	Cr	00	5215.737		000 N
5200.590	V	0	5216.437	Fe	3
5200.989		0000 N	5216.648		00
5201.260	Ti	000	5217.552 s	Fe	3
5201.458		0000 N	5217.836		0000 N
5201.771		0000 N	5218.030		0000
5202.125		000	5218.085	Fe	0
5202.249		000	5218.369	Fe	1
5202.439 } s	Fe?	2	5218.675		0000
5202.516 } s	Fe	4	5219.186		0000
5202.945		0000	5219.875	Ti	0
5203.118		0000	5220.045		0000
5203.658		000	5220.250		000
5204.414		0000	5220.358	Ni	0
5204.680 } s	Cr	5	5221.078		000
5204.768 } s	Fe	3	5221.197	Cr	00
5205.113		0000	5221.928	Cr	0
5205.467		0000	5222.556	Cr	00
5205.897	Y	0	5222.849	Ti, Cr	00
5206.215	Cr-Ti	5	5223.033		0000 N
5206.372		00	5223.351	Fe	0
5206.712		000	5223.529	Ti	0000
5206.986		0000	5223.705		0000
5207.259		0000	5223.791		000
5207.791		000 N	5224.062		0000 Nd?
5208.038		0000	5224.239	Cr	000 N
5208.111	Ti	00	5224.471	Ti	0
5208.276		000	5224.712	Ti, Cr	00
5208.596	Cr	5	5224.885		0000
5208.776	Fe	2	5225.101	Cr	0
5209.779 x		0000	5225.198	Cr, Ti, Fe	00
5209.949		0000	5225.513		0000
5210.059		000	5225.695 s	Fe	2
5210.204		0000	5225.877		0000
5210.421		0000	5225.974	Cr	000

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
5226.224		0000	5242.658 s	Fe	2
5226.364		0000	5243.346		000
5226.549		0000	5243.526	Cr	00
5226.707	Ti-	2	5243.635		0000
5227.043	Fe-Cr	3	5243.946	Fe	1
5227.362	Fe	5 d?	5244.702		000 N
5227.639		0000	5245.118		0000
5227.902		000	5245.801		0000
5228.049		0000	5245.901		0000
5228.268	Cr	000	5246.170		0000
5228.546		1	5246.310		0000
5228.727		0000	5246.733		0000
5230.030 s	Fe	4	5246.946		000
5230.225		0000	5247.229	Fe	1
5230.382	Co, Cr	00	5247.466	Ti	000
5230.554		0000	5247.737	Cr	2
5230.867		000 N	5248.091	Co	000 N
5231.151		0000	5248.550		000
5231.578		000	5249.163		0000
5232.681		000	5249.279	Fe	00
5233.005		0000	5249.593		0000
5233.122 s	Fe	7	5249.751		0000
5234.022		0000	5250.193		0000
5234.255		0000	5250.385 s	Fe	2
5234.380		000	5250.602		0000 N
5234.603		0000 N	5250.817 s	Fe	3
5234.791		2	5251.085		0000 N
5235.040		0000	5252.146	Fe	0
5235.202		0000	5252.276	Ti	000
5235.353	Co	000	5253.205		00
5235.557	Fe	1	5253.421		0000
5235.672	Ni	00	5253.633 s	Fe	2
5236.373		0	5253.854		0000 N
5236.549		000	5254.132		0000 N
5237.254		0000	5254.830		0000
5237.493	Cr?	1	5255.121	Fe	3
5238.011		0000	5255.295	Cr	0
5238.416		0000	5255.492	Mn	0 d?
5238.742	Ti	000 N	5255.687		0000
5239.137	Cr	00	5255.831		000
5239.992		1	5255.912		000
5240.310		0000	5255.973	Ti	0000
5240.523		0000	5257.100	Sr?	00
5240.639		000	5257.246		0000 N
5241.040		000	5257.529		0000 N
5241.347		0000	5257.814		0
5241.624		0000	5258.000		000 N
5242.094		0000	5259.261		0000 N
5242.238		000	5259.660		000 N
5242.450		0000 N	5259.912		0000

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
5260.142		000	5270.235		000
5260.438		0000	5270.438 s	Ca	3
5260.561 s	Ca	0	5270.558 s	Fe	4
5260.840		0000	5271.228		00
5260.945		0000	5271.464		00
5261.669		0000	5271.796		000
5261.876 s	Ca-Cr	3	5272.017		0000
5262.130		000 N d?	5272.171	Cr	00
5262.321 s		1	5272.436	Fe	000
5262.419 s	Ca	3	5272.574		000
5262.631		0000	5273.339 s	Fe	3
5262.791		000	5273.558 s	Fe-Cr	2
5263.056		00	5273.770		0000 N
5263.239		0000	5274.408		00
5263.486	Fe	4	5274.575		000
5263.669	Ti	000	5274.702		00
5263.890		000	5274.959		0000 N
5264.038	Fe	0	5275.148		0
5264.163		0000	5275.340	Cr	00
5264.329 s	Cr	4	5275.454		1
5264.415 s	Ca	3	5275.641		0000 N
5264.570		000	5275.762		0000
5264.759		000 N d?	5275.926	Cr	1
5264.976		0	5276.169 } s	Fe?	3
5265.146		0000 N	5276.237 } s	-Cr?	2
5265.321	Cr	00	5276.344	Co	000
5265.423		000	5276.612		0000 N
5265.591	Co	0000	5277.047		000
5265.729 s	Ca	3	5277.480		00
5265.893 s	Ni-Cr	2	5278.420		00 N
5266.141	Ti	0	5278.747		0000
5266.246		000 N	5278.960		00
5266.482		000	5279.130		000
5266.639		000	5279.349		0000
5266.738 s	Fe	6	5279.481		000
5267.203		000	5279.843		00
5267.273		000	5280.048		0
5267.447		00	5280.239		00
5267.658		0000	5280.458	Cr	000
5267.825		000 N	5280.540	Fe	1
5268.355		0000	5280.799	Co	00
5268.515	Ni	0	5281.099		0000Nd?
5268.670		000	5281.333		000
5268.784	Co	00	5281.491		00 N
5268.972		0000	5281.681		000 N
5269.125		000	5281.844		000
5269.586		00 N	5281.971 s	Fe	5
5269.723 s	Fe	8 d?	5282.339		0000
5269.863		000 N	5282.576	Ti	00
5270.076		0000	5283.331		0000

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
5283.613	Ti, Co	00	5300.152		00
5283.802 s	Fe	6	5300.578		000
5284.087		000	5300.735		0000
5284.281	Ti	1	5300.929 s	Cr	2
5284.453		0000	5301.094		0000
5284.601	Fe, Ti	00	5301.218	Co	00
5284.787		00	5301.485		000
5284.940		0000	5301.666		0000
5285.300	Ni	0	5302.048		000
5285.431		000	5302.225		000
5285.557		0000	5302.480	Fe	5
5285.819		000	5302.738		0000
5287.351	Cr	000	5302.829		000
5287.741		0000 N	5303.122		0000
5287.958		000	5303.401		0
5288.389		000	5303.591		000
5288.548		0000	5303.738		000
5288.705 s	Fe	2	5304.018		00
5288.974		000	5304.355	Cr	0
5289.446		000	5304.610		0000
5289.676		000	5304.735		000
5289.988		000	5305.167		000 d
5290.984		000	5305.602		0000
5291.820		000 N	5306.040		0
5292.388	Awv?	000 N	5306.331		0000
5292.569		0000	5306.665		000
5292.762	Fe	0	5307.039		0000
5293.044		000	5307.140		0000
5293.210	Awv?	00	5307.402		000
5293.341	Awv?	00	5307.541 s	Fe	3
5293.543		000	5308.385		0000
5293.946		0000	5308.599		0
5294.134	Fe	0	5308.863		00
5294.290		0000	5309.064		000
5294.579		0000	5309.357		0000
5294.726		00	5309.630		0000
5295.241		0000	5310.227		0000
5295.485	Fe	0	5310.417		000
5295.955	Awv?	00	5310.659		000
5296.243		000	5310.866		0
5296.657		0000	5311.102		000
5296.872 s	Cr	3	5311.310		0000
5297.407	Cr, Ti	000	5311.650		000
5297.555	Cr	2	5311.804		000
5298.194	Cr	1	5311.962		000
5298.455	Cr	4	5312.435		000
5298.672	Ti	0	5312.666		000
5298.957	Fe	0	5312.835		00
5299.005		0000	5313.031	Cr	0
5299.804		0000	5313.253		000

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
5313.422		000 N	5328.747	Fe	2
5313.587	Co	000	5328.919		0000
5313.758		1	5329.096		000 d?
5313.931		0000	5329.329	Cr	3
5314.447		0000 N	5329.975	Cr	0
5314.916		000 N	5330.179	Fe	2
5315.103		000	5330.748		000
5315.252	Fe	1	5331.377		0000
5315.960		000 N	5331.641	Co	00 d
5316.390		0000	5331.944		000
5316.572		0000	5332.545		000
5316.790 s	Fe	4	5332.849	Co, Fe	1
5316.906 } s	Co	0	5333.089 s	Fe	4
5316.958 }		2	5333.334		000
5317.249		0000	5333.432		000
5317.724		00 N d?	5333.832	Co	000
5318.215		0000	5333.949		000
5318.534		00 N	5334.140		0000
5318.777		0000	5334.403		000
5318.955	Cr, Fe	0	5334.520		000
5319.225		00	5335.050	Co	1
5319.392		000	5335.147		0000
5319.502		000	5335.547		0000
5319.999		00	5335.770		0000
5320.220	Fe	0	5336.356		000
5321.005		000 N	5336.478		0000
5321.293	Fe	2	5336.660		0000
5321.976	Mn	000 N d?	5336.792		0000 N
5322.227	Fe	3	5336.974	Ti,-	4
5322.994		000	5337.910		0
5323.687		0000	5337.946		00
5323.971		0000	5338.517		00 N
5324.274		0000	5338.727		000
5324.373 s	Fe	7	5338.927		000
5324.881		0000	5339.403		000
5325.460	Co	00	5339.609	Co	00
5325.569		0000	5339.719		000
5325.738		2	5339.878		0000
5326.139		000 N	5340.121	Fe	6
5326.331	Fe	1	5340.375	Co	00
5326.535		0000	5340.639	Cr	0
5326.682		0000	5340.852		000
5327.003		00	5340.962		0000
5327.445		000	5341.213	Fe	7
5327.917		0000	5341.337	Mn	1
5328.074		00	5341.514		00
5328.236	Fe	8 d?	5341.670		000
5328.367		000	5341.933		0000
5328.515	Cr	2	5342.055		0000
5328.696	Fe	2	5342.276		000

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
5342.409		000	5357.383		00
5342.713		000 d	5358.306		00
5342.890	Co	1	5358.476		0000
5343.148		0000	5358.668		0000
5343.310		0000	5358.853		000
5343.411		0000	5359.127		000 N
5343.570	Co	0	5359.389	Co	00
5343.622	Fe	2	5359.714		000
5344.646	Mn	00	5359.910		000
5344.767		000 N	5360.330		0000 N
5344.942	Cr	00	5360.665		0000
5345.729		000	5360.903		0000
5345.991	Cr	5	5361.115		0000
5346.274		00	5361.343		0000
5346.523		000	5361.565		000
5346.731	Fe	0	5361.697		000
5347.004		00	5361.813 s		1
5347.156		0000	5362.365		0000
5347.277		000	5362.944 s	Fe, Co	1
5347.500		0000	5363.058 s		3
5347.712		00	5364.359		000
5347.898		00	5364.615		000
5348.259		000	5365.069	Fe	5
5348.511	Cr	4	5365.416		0000
5348.947		000	5365.596	Fe	3
5349.283		000	5366.616		00
5349.473		0000	5366.827		000
5349.653 s	Ca	4	5366.950		000
5349.928	Fe	1	5367 669 s	Fe	6
5350.059	Mn	00	5367.962		0000
5350.281		00	5368.083		0000
5350.547		00	5368.311		0000
5350.688		0000 N	5368.490		000
5350.976		0000 N d?	5368.626		000
5351.261	Ti	00	5368.741		000
5351.832		0000	5369.044		0000
5352.024		000	5369.125		0000
5352.234	Co	1	5369.348		0000 N
5352.421		0000	5369.550		000
5352.591		000	5369.782	Co-Ti	1
5353.178		000	5370.166 s	Fe	6
5353.350		0000 N	5370.522	Cr	00 N
5353.571 s	Fe, Cr	3	5371.528	Ni	1
5353.702	Co	0	5371.656 } s	Cr?	4
5354.714		0000	5371.734 }	Fe	3
5354.916		0000	5372.121		000
5355.088		0000	5373.839		0000 N
5355.921		00	5373.905	Fe, Cr	2
5356.270		000	5374.142		0000
5357.178		000	5374.349		000

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
5374.610		000	5387.165	Fe, Cr	0
5374.962		000	5387.323		0000
5375.086		0000	5387.478		000 N
5375.371		000	5387.680	Fe	00
5375.516		000	5387.769	Cr	00
5376.068		000	5387.926		0000
5376.320		000	5388.192		000
5376.656		000	5388.360		0000
5376.867		0000	5388.550		00
5377.028	Fe	0	5388.713		000
5377.252		00	5388.989		000
5377.388		000	5389.371		000
5377.505		0000	5389.505		0000
5377.606		0000	5389.683 s	Fe	3
5377.800	Mn	2 N	5389.875		0000
5377.991		000	5390.047		00
5378.122		0000	5390.203		000
5378.426		000	5390.573	Cr	000
5379.338		0000	5390.725		0
5379.519		0000	5390.974		0000
5379.625		0000	5391.267		0000
5379.775 s	Fe	3	5391.660	Fe	2
5380.086		0000	5391.820	Fe	1
5380.258		0000	5391.990		0000
5380.516		0 N	5392.212		00 N
5380.909		00 N d?	5392.528	Ni	00
5381.221	Fe	2	5393.375 s	Fe	5
5381.362		0000	5393.584		000
5381.514	Co	0000	5394.404		0000
5381.686		0000	5394.551		000
5381.980	Co	000	5394.839	Mn[1]	{ 1
5382.232		0000	5394.913		{ 1
5382.469		0	5395.209		0000 N
5382.951		0000	5395.422		0
5383.209		000	5395.668		000
5383.325		0000	5396.196		0000 N
5383.578 s	Fe	6	5396.448		00
5383.963		0000	5396.778	Ni	000 N
5384.267		0000	5396.935		000
5384.398		0000	5397.107		000
5384.833		000	5397.344 s	Fe	7 d?
5385.071		0000	5397.822	Fe	1
5385.329		000	5397.993		0000
5385.501		0000	5398.256		0000
5385.785		00	5398.486	Fe	3
5386.089		000	5399.065		000
5386.301		0000	5399.675	Mn	1 N d?
5386.534	Fe	1	5399.974		0000
5386.797		0000 N	5400.462		0000 N
5386.989		0000	5400.624		0000

[1] Compound lines measured as double in solar spectrum.

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
5400.711	Fe	3	5413.302	A?[2]	00 N
5400.831	Cr	0 N	5413.616		0000 N
5401.472		0	5413.889	Mn[1]	00 N
5401.904		000 N d?	5414.117		0000
5402.151		0000	5414.279		00
5402.273	V	00	5414.547	A?	0000 N
5402.799		0000	5415.083		0000 N
5402.982	V	0	5415.416 s	Fe-V	5
5403.670		0000	5416.282		0000
5404.028	Fe	2	5416.587		0000
5404.357	Fe	5	5417.247	Fe	0
5404.750		00	5418.357		000 N
5404.883		00	5418.463		0000
5405.047		0000	5418.979	Ti?	1
5405.192	Cr	00	5419.136	A?	0000
5405.341		000	5419.313	A?	0000
5405.554		1	5419.421	A?	0000
5405.695		0000	5419.627		0000
5405.989 s	Fe	6	5420.113		000
5406.388		0000 N	5420.295		0000 Nd?
5406.543		00	5420.510	Mn[2]	0 N
5406.687		0000	5420.613		0 N
5406.808		0000	5420.821	A?	0000 N
5406.980		1	5421.134		00
5407.243		0000 N	5421.381		0 N
5407.375		0000 N	5421.614		000
5407.587	Mn[1]	0	5421.783		0000 N
5407.688		0	5422.049		00
5407.820		00	5422.370		00
5408.028		0000 N	5422.719		0000
5408.285		0000 N	5422.866		0000
5408.407		0000 N	5423.160		0000
5408.569		0000 N	5423.689		000 N
5408.792		0000 N	5423.802		0000
5409.024		000	5423.963		000
5409.131		0000	5424.170		000 N
5409.339	Fe	2	5424.290 s	Fe	6
5409.632		0000 d?	5424.406		0000 N
5409.823	Ti	000	5424.761		000
5410.000 s	Cr	4	5424.860	Ni	1
5410.259		0000 N	5425.464		1
5410.633		0000 N	5425.832		000
5411.124	Fe	4	5426.474		00
5411.428	Ni	1	5427.036		000 N
5411.596		000	5427.431		0000
5411.764		0000	5428.018		000
5412.211		000	5428.534		000
5412.391		0000	5428.918		000
5412.779		000	5429.057		000
5412.997	Mn	00	5429.186		0000

[1] Compound lines in both Mn and Sun.

[2] A means "atmospheric line."

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SEVEN NEW VARIABLE STARS.[1]

By M. FLEMING.

SINCE the discovery of eleven new variable stars at this Observatory was communicated to THE ASTROPHYSICAL JOURNAL in a letter dated April 9, 1895, seven other variables have been discovered here. Five of them were found in the examination of the photographs of stellar spectra taken at Cambridge and at the Arequipa Station in Peru, forming part of the work of the Henry Draper Memorial. These stars have spectra of the third type, having also the hydrogen lines bright. This peculiarity led to their being suspected of variability, since many known variable stars of long period possess this class of spectrum. Two were found from a comparison of the photographic chart plates with the maps of the *Durchmusterung*, while selecting and checking the selection of the faint stars for standards of stellar magnitudes. The variables are enumerated in the following table which gives the constellation, the designation, the approximate right ascension and declination for 1900, the catalogue magnitude of the star and the magnitudes when brightest and when faintest, as derived from the photographs:

Constellation	Designation	R. A. 1900	Dec. 1900	Mag.	Mag. Br.	Mag. Ft.
Eridanus....	*C.D.M.*−24°1960	$3^h\ 51^m.0$	−24° 20′	8.6	7.2	11.0
Orion.....	*B.D.* +0° 939	5 0 .2	+ 1 2	6.0	8.8	10.6
Puppis.....	*Z.C.* 7^h3056	7 42 .6	−41 57	9½	9.8	12.1
Cancer	.....	9 4 .0	+25 39	—	9.6	<13.5
Hydra.....	*S.D.* − 7°2873	9 37 .7	− 7 38	9.0	9.7	10.6
Libra.....	*S.D.* −14°4228	15 27 .7	−14 59	9.4	8.5	<12.3
Ursa Minor..	.....	15 33 .3	+78 58	—	8.4	11.4

—Eridani. *C.D.M.* −24° 1960. The magnitudes of this star as derived from photographs taken on September 6, October 20,

[1] Communicated by Edward C. Pickering, Director of the Harvard College Observatory.

November 6, 1889; September 13, 1890; January 30, February 1, October 22, December 17, 1891; December 14, 1892; November 18, November 20, 1893; August 13, August 14, September 22, October 27, November 6, November 10, November 16, and December 13, 1894, are 9.8, 7.2, 7.7; 9.1; 9.9, 9.8?, 9.0, 7.9; <9.8; 9.8, 9.6; 8.4, 8.3, 8.0, <8.4, 9.4, 9.8, 9.8, and 11.0 respectively.

—Orionis. *B.D.*+0°939. The variation in the light of this star was discovered by Miss E. F. Leland. It presents an especial interest on account of the apparent length of its period. It was bright in 1879 and again in 1891, and faint in the intermediate years. As, however, all the observations were made at about the same part of the year further observations are required, as it is still possible that the period may be a little less or a little greater than one year. Of the variability there can be no doubt. While it is proved by the photographs, the visual observations alone are sufficient to establish it. Thus four of the excellent Potsdam observations give the results 6.08, 5.99, 5.87, and 6.38. No one who looked at it last winter could doubt that it was fainter than the sixth magnitude. In fact the meridian photometer on six nights gives the results 7.10, 7.23, 7.02, 7.22, 7.13, and 7.22. In 1880 the meridian photometer gives its magnitude as 5.8; in 1881, 6.7; in 1882, 6.8; in 1883, 6.6; in 1885, 6.8; in 1894, 6.8; and in 1895, 7.2. Its magnitudes as derived from photographs taken on November 9, 1885; February 29, September 28, 1888; December 29, 1890; January 26, January 26, December 11, December 11, 1891; January 4, January 8, January 21, December 20, December 22, December 28, December 29, 1892; September 20, October 2, and November 26, 1893 are 10.0; 9.8, 9.6; 9.0; 8.9, 8.8, 10.0, 10.0; 9.8, 9.5, 9.6, 10.3, 10.4, 10.2, 10.3; 10.6, 10.4, and 10.1 respectively.

—Puppis. *Z.C.* 7^h 3056. *C.D.M.* −41° 3363. The magnitudes of this star as derived from photographs taken on October 3, October 22, November 13, 1889; September 27, September 27, October 24, October 24, October 26, October 26, 1893; April 18, October 19, and November 24, 1894 are < 10.6, < 10.8, 9.8;

11.8, 12.1, 10.4, 10.0, 10.0, 9.9; 10.8, 10.7, and 9.9 respectively.

—Cancri. R.A. $9^h\ 4^m.0$; Dec. $+25^\circ\ 39'$. The magnitudes of this star as derived from photographs taken on December 6, 1889; December 7, December 9, December 14, December 18, December 29, 1890; March 26, 1891; February 15, March 7, April 9, 1892; March 12, March 18, March 31, April 5, November 22, 1893; January 2, January 25, March 30, November 15, 1894; January 23, March 5, May 9, and May 23, 1895, are 11.5; 10.2, 10.2, 10.4, 10.7, 10.7; 11.6; 12.2, 12.8, <13.5; 11.9, 12.3, <12.0, <12.1, 10.6; 9.6, 10.0, 12.0, 11.8; 9.8, 10.0, 12,0, and <12.1 respectively.

—Sextantis. *S.D.* $-7^\circ 2873$. The variation in the light of this star was discovered by Miss L. D. Wells. Its magnitude as derived from photographs taken on January 24, April 9, 1888; December 9, 1889; March 25, 1891; February 15, March 6, March, 14, March 30, 1892; February 24, March 15, November 22, 1893; April 19, December 17, 1894; February 11, February 13, April 10, April 10, April 11, April 11, April 11, April 16, April 16, April 17, April 17, April 18, April 18, April 20, April 23, April 23, April 25, April 25, May 1, May 1, May 2, May 3, May 3, May 6, May 7, May 7, May 9, and May 23, 1895 are 9.8, 9.8; 10.4; 10.6; 9.9, 9.8, 9.9, 9.8; 9.9, 9.9, 9.9; 10.0, 9.9; 9.8, 9,7, 9.9, 10.1, 9.7, 9.9, 9.9, 9.9, 9.9, 9.9, 9.9, 9.9, 9.9, 10.2, 10.0, 9.9, 10.1, 10.0, 10.0, 10.0, 10.2, 10.3, 10.2, 10.2, 9.9, 10.2, 10.4, and 10.4 respectively. These results were confirmed by measures made by Mr. O. C. Wendell with a polarization photometer attached to the 15-inch equatorial.

—Libræ. *S.D.* $-14^\circ 4228$. The magnitudes of this star as derived from photographs taken on February 28, May 17, 1888; July 18, 1890; May 16, May 16, June 3, June 23, June 23, 1891; May 10, May 10, May 10, May 11, 1892; May 7, May 7, July 22, July 27, 1893; May 13, June 14, June 17, June 18, and June 20, 1895 are <12.3, 10.8; <11.4; <11.8, <11.0, <11.5, <11.8, <11.9; <10.8, <10.6, <10.4, <8.9; <11.8, <11.7, 10.6, 10.7; 8.9, 8.5, 8.5, 8.6, and 8.7 respectively.

—Ursæ Minoris. R.A. $15^h\ 33^m.3$; Dec. $+78^\circ\ 58'$. The mag-

nitudes of this star as derived from photographs taken on March 9, August 28, September 29, October 1, November 10, 1890; July 16, 1891; April 11, 1892; August 15, August 15, August 26, 1893; August 17, October 17, November 10, November 12, November 12, December 29, 1894; January 1, January 2, April 23, April 25, May 1, May 2, May 3, May 6, May 7, May 16, May 22, May 23, May 29, June 7, June 14, June 17, and June 18, 1895 are 11.4, 8.4, 8.6, 8.4, 9.3; 8.4; 9.3; 9.8, 9.8, 10.3; 11.2, 11.3, 10.6, 10.7, 10.5, 8.9; 8.9, 8.8, 9.2, 9.4, 9.4, 9.2, 9.03, 9.4, 9.4, 9.4, 9.8, 9.7, 10.0, 10.2, 10.4, 10.4 and 10.4 respectively.

The photographs of the above variables have been examined, and the variability of the stars confirmed by Professor E. C. Pickering.

HARVARD COLLEGE OBSERVATORY,
Cambridge, Mass., July 5, 1895.

ON THE EXISTENCE OF LAW IN THE SPECTRA OF SOLID BODIES, AND ON A NEW DETERMINATION OF THE TEMPERATURE OF THE SUN.

By F. PASCHEN.

IN THE ASTROPHYSICAL JOURNAL for June 1895 there is an article by Mr. H. Ebert, in which the temperature of the Sun is determined by an extrapolation based on Langley's energy curves for heated solid bodies, and a relation between the wave-lengths of the maxima and the temperature which has been deduced from these curves by Mr. H. Rubens.[1] The wave-length of the maximum ordinate of the energy curve for the normal solar spectrum is also given. According to Mr. Langley[2] it is about $0^{\mu}.5$.

I will not enter into the discussion of valence charges of atoms and the constitution of the Sun which is found in this article, but will confine myself to a consideration of the experimental basis which has been mentioned, *i. e.*, the law ascribed to Rubens.

Many previous attempts to deduce a similar law from the observations of Langley have been made. H. F. Weber,[3] M. W. Michelson,[4] R. von Kövesligethy,[5] Lord Rayleigh[6] and others have concerned themselves with the same question. The formula of Michelson is exactly the same as that of Rubens, but, although it was published some years ago, it seems to have been overlooked by Rubens as well as by Ebert. In a number of the articles that I have mentioned a value of the solar temperature has been determined in quite the same manner as by Ebert, and with essentially the same result (see for example the article

[1] H. RUBENS, *Wied. Ann*, **53**, 284. 1894.

[2] S. P. LANGLEY, *Researches on Solar Heat.* Washington, 1884.

[3] H. F. WEBER, *Sizungsber. Berlin*, 1888, II., 933.

[4] M. W. MICHELSON, *Jour. de Phys.*, II., **6**, 467, 1887.

[5] R. v. KÖVESLIGETHY, *Grundzüge einer theoret. Spectralanalyse*, Halle.

[6] LORD RAYLEIGH, *Phil. Mag.*, **27**, 460, 1889.

by Michelson), although this fact also seems to have been unnoticed by him.

In the application of such methods it is first of all necessary that the law in question, which is to be used in an extrapolation extensive enough to reach the temperature of the Sun, should hold accurately within the limits of observation. This condition has not been met hitherto by any means,—certainly not in the table of Rubens. Most of the computers, who, like Rubens, have used these data, have therefore laid stress on the necessity of further experimental work.

It may be observed, in this connection, that certain precautions, which it is not permissible to neglect, have been omitted in evaluating Langley's curves. For example, neither Michelson, Kövesligethy, nor Rubens has transformed Langley's prismatic energy curves into the corresponding curves for the normal spectrum. But it is here not sufficient to merely introduce the wave-lengths in place of the deviations recorded by the prism; the ordinates, representing the galvanometer deflections, must be reduced to those which would have been obtained if in every region of the spectrum the same range of wave-lengths fell on the bolometer strip. On account of the characteristic dispersion of a prism the effect of this reduction is very sensibly to displace the maximum of the energy curve for the long waves in question, toward the side of longer wave-lengths. If Langley's curves are treated in this manner, as they were in some cases by Langley himself, by means of the dispersion of rock salt which he determined, and which long ago permitted the transformation to be effected with fairly close approximation as far as the region $5^{\mu}.3$, Michelson's relation

$$\lambda_{\text{max.}} \times \sqrt{\text{abs. temp.}} = \text{const.}$$

does not hold even approximately. Still other, though less fatal, oversights may be found in the computations of the gentlemen I have referred to.

As I believe that it is in the highest degree important to make a series of elaborate and exact measurements in the spectra of solid bodies, in order to provide a secure experimental basis

for theoretical investigations, I have been engaged in researches of this kind for over two years.

The first thing to be considered is to find a body which reflects light of all wave-lengths as little as possible, or as uniformly as possible, and which thus affords the closest possible approximation to the "absolutely black body" of Kirchhoff; since for such a body there are no disturbing complications to effect the law of distribution of energy in the spectrum. Our knowledge of this subject has hitherto amounted to little more than nothing, and I have therefore investigated the surfaces of various bodies, in the same manner that Jacques[1] did sixteen years ago, but with materially better means for exploring the spectrum and for determining temperatures. The apparatus which I have used for this purpose, consisting of the calibrated platinum and platino-rhodium thermo-element of Le Chatelier, and the spectrobolometer of Langley, in which I have introduced a number of refinements, is perhaps the best that can be applied to such an investigation at the present time. A complete account of my measurements must be reserved for another occasion, as the computation of the hundreds of curves consumes an extraordinary amount of time. I have not considered it necessary to publish a preliminary account since Rubens' paper was printed, inasmuch as his table contains nothing that has not been given by Michelson and others, although the paper containing the results that I now communicate has been lying in my desk almost from the beginning of the year, awaiting a further revision. But on account of the attention which seems to have been attracted by Rubens' computation, I feel constrained to publish a brief outline of some results which I now regard as established, since they are in direct contradiction to Michelson's formula and lead to quite different conclusions from those which Ebert has regarded as justifiable.

With regard to the arrangement of the apparatus in these investigations I will here merely refer to my various papers on bolo-

[1] W. JACQUES, *Distribution of heat in the spectra of various sources of radiation*. Baltimore, 1879.

metric measurements in *Wiedemann's Annalen.* All the essential parts of the apparatus—the thermo-element with its method of calibration, the spectrobolometer and the galvanometer—are described there at length. These earlier investigations, particularly those relating to the absorption of gases and the dispersion of fluorite, may be regarded as a necessary and important preparation for the work now under consideration.

The substances which were investigated,—polished platinum, the carbon filament of an incandescent lamp (the carbon was prepared in benzine and was therefore brightly reflecting, while the lamp was furnished with a window of fluorite), black copper oxide, oxide of iron, and lampblacked platinum,—gave very different spectra at the same temperature. In the case of each body, however, the wave-length of maximum energy moved toward the upper end of the spectrum with increasing temperature, as Langley had already found it to do in the case of lampblacked or oxydized copper. For different substances this displacement took place in a different manner, a fact which also seems to have been previously indicated by the work of W. H. Julius.[1] According to my measures blackened platinum gives ~~the~~ higher ~~position of the maximum of energy~~ ordinates at all wave lengths for the same temperature than any other substance. It has been investigated at temperatures up to 450° C. Next comes oxide of iron, which gives somewhat smaller ordinates in the infra-red, these ordinates, moreover, being proportionally smaller as the wave-length increases. Measures have been made up to about 1100° C. Then comes oxide of copper, investigated as far as 900° C., then the carbon filament, and finally the bright platinum, with which measures have been made up to a temperature of 1500° C., and which gives by far the smallest ordinates in the infra-red of all these substances. At 5μ its radiation is only about one-tenth as intense as that of oxide of iron at the same temperature.

These differences are probably determined by differences in the selective reflection of the substances. It follows that oxide

[1] W. H. JULIUS, *Licht- und Wärme-Strahlung verbrannter Gase.* Preisschrift, Berlin.

of copper, oxide of iron, and particularly lampblacked platinum are the closest approaches to an "absolutely black body."

For oxide of ~~copper~~ iron I have transformed a series of energy curves into normal energy curves, in the manner described at length by Langley. Further corrections have also been applied —for the different angles of incidence on the prisms in different spectral regions and the correspondingly different losses by reflection thereby produced, and for the selective reflection of the two silvered concave mirrors which are used in my apparatus to form an image of the spectrum. These last two corrections have very little or no effect on the main result. On the other hand, a very important correction which I had previously studied in some detail, consists in filling out the gaps in the energy curve due to the absorption bands of carbon dioxide and water vapor in the observing room. Below 6μ this process of piecing out the energy curve is no longer possible with the necessary precision, on account of the broad absorption bands of water vapor in that region. Hence I could not determine the maxima for greater wave-lengths than 5μ, although the energy curves of the prism were measured below this point, for temperatures down to 70°C. In Langley's curves most of these absorption bands, and among them those most prejudicial to accuracy, do not occur. Finally, at 7μ the absorption of my fluorite prism begins to be perceptible, so that for this reason also the computation of even the approximate course of the energy curve is very uncertain, if not impossible.

The curves which were obtained after these corrections had been applied exhibited a conformity to law in a number of different ways. The most important laws are the following:

1. *For the normal energy curve the following relation holds in the neighborhood of the maximum:*

$$\lambda_1 \times \lambda_2 = \lambda^2_{max} .$$

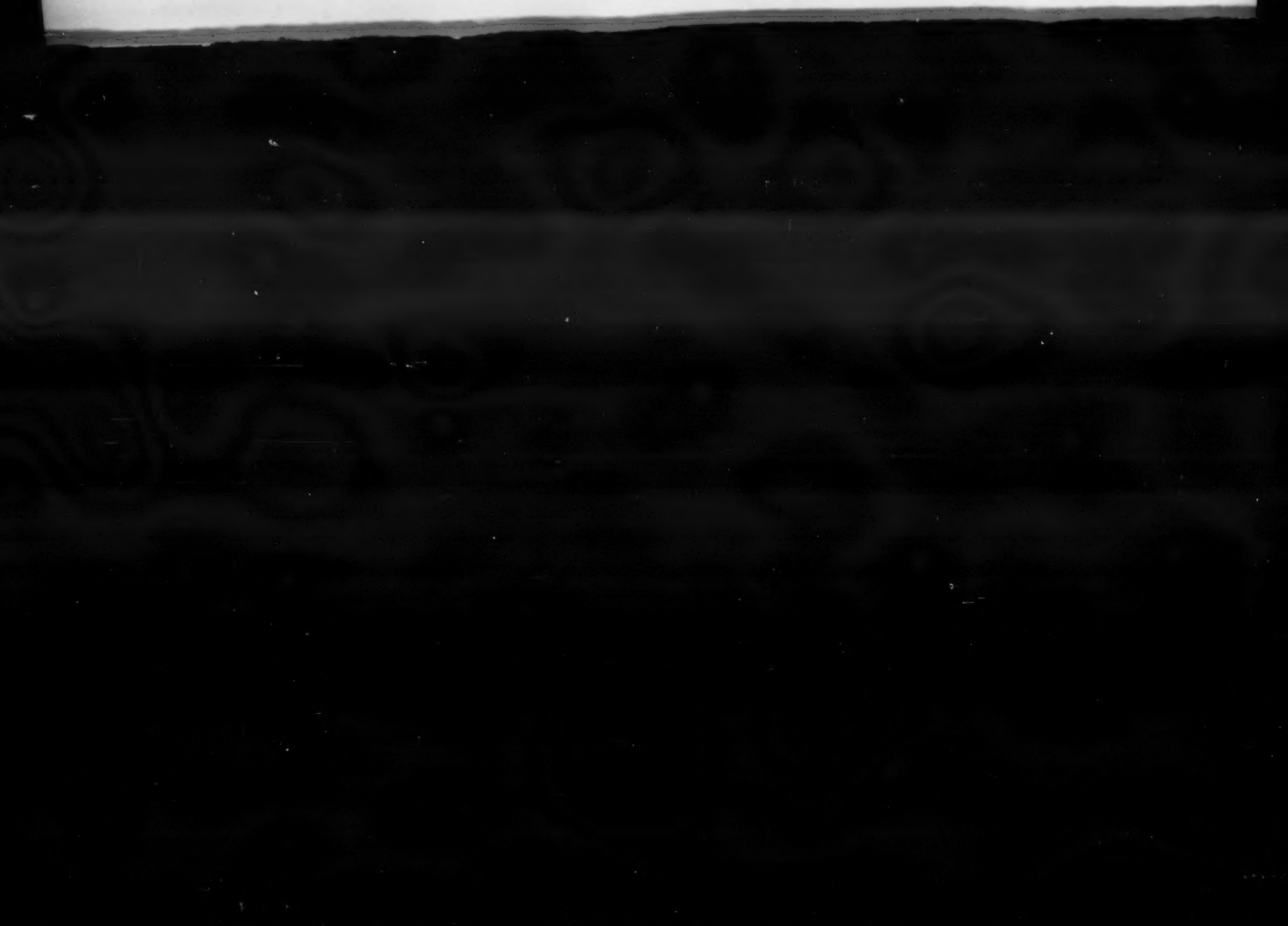
In this equation λ_1 and λ_2 are two wave-lengths of equal intensity, one above and one below the wave-length (λ_{max}) of the maximum. This relation, which holds, within the limits of error of observation, only in the vicinity of the maximum, is especially

ERRATA.

In The Astrophysical Journal, **2**, October, 1895, on p. 205, for "According to my measures blackened platinum *gives a higher position of the maximum of energy* for the same temperature than any other substance" read

"According to my measures blackened platinum *gives higher ordinates at all wave-lengths* for the same temperature than any other substance."

Also on p. 206, third line, for "*oxide of copper*" read "*oxide of iron.*"



useful for determining the exact position of the maximum by means of λ_1 and λ_2. It also renders unnecessary the filling out of the depressions due to absorption which have been mentioned, even in the most unfavorable cases where the maximum falls exactly at the place of an absorption band, such as the band of carbon dioxide at $4^{\mu}.27$ or the band of water vapor at $2^{\mu}.66$.

As a proof of the relation I give a few determinations of the position of the maximum ordinate. They are based upon the relation and at the same time demonstrate its correctness:

Temp. = 295° C.
Temp. of screen = 16°.2 C.

λ_1	λ_2	$\sqrt{\lambda_1 \lambda_2}$	
4.280	4.800	4.532	
4.000	5.080	4.508	
3.895	5.185	4.494	λ_{max} 4.503
3.543	5.640	4.471	
3.175	6.410	4.512	
2.590	8.060	4.569	
2.295	8.950	4.532	

Temp. = 441° C.
Temp. of screen = 15°.2 C.

λ_1	λ_2	$\sqrt{\lambda_1 \lambda_2}$	
3.508	3.785	3.644	
3.382	3.938	3.650	λ_{max} 3.652
3.290	4.058	3.654	
3.220	4.163	3.662	
3.162	4.258	3.669	
3.035	4.505	3.697	
2.972	4.658	3.722	
2.913	4.800	3.739	
2.868	4.935	3.763	

Temp. = 888° C.
Temp. of screen = 15°.6 C.

λ_1	λ_2	$\sqrt{\lambda_1 \lambda_2}$	
2.193	2.375	2.282	
2.160	2.420	2.287	
2.090	2.505	2.288	λ_{max} 2.287
2.037	2.570	2.288	
1.992	2.630	2.290	
1.812	2.977	2.323	

Temp. = 937° C.
Temp. of screen = 15°.2 C.

λ_1	λ_2	$\sqrt{\lambda_1 \lambda_2}$	
2.155	2.255	2.205	
2.110	2.280	2.194	
2.085	2.301	2.191	λ_{max} 2.195
2.045	2.353	2.194	
1.948	2.458	2.189	

2. *The wave-length of the maximum is to a very close approximation inversely proportional to the absolute temperature.*

This relation may be proved by means of the following short table, in which the first column contains the temperature T of the curve in centigrade degrees, the second the corresponding absolute temperature, the third the wave-length of the maximum, and the last the product of this wave-length and the absolute temperature.

T	Abs. T	λ_{max}	$\lambda_{max} \times$ Abs. T.
228	501	5.03	2520
262	535	4.83	2584
295	568	4.503	2558
299	572	4.46	2551
310	583	4.396	2564
388	661	3.908	2567
437	710	3.578	2542
441	714	3.652	2607
528	801	3.250	2603
698	971	2.670	2593
703	976	2.658	2594
824	1097	2.389	2621
841	1114	2.375	2648
888	1161	2.287	2655
937	1210	2.195	2656
973	1246	2.166	2699
1009	1282	2.125	2727

This table represents about half of my best measures with oxide of iron. There are several possible reasons for the fact that $\lambda_{max} \times$ abs. temp. is too small for low temperatures, and I will mention them below.

First; with respect to the radiation of the greater wave-lengths, oxide of iron does not behave precisely like an absolutely black body. The ordinates for the larger waves become greater for the same temperature if its surface is coated with lampblack, and the amount of increase, moreover, grows with increasing wave-length. Hence the maximum of the energy curve for oxide of iron is higher than it would be for an absolutely black body; it is displaced toward the upper end of the spectrum. As an example, I obtained the following values when the surface of oxide of iron was coated with lampblack:

T	λ_{max}	$\lambda_{max} \times$ Abs. T.
372	4.025	2616
348	4.214	2617

The product for unsmoked oxide of iron at 360° C. is, according to the table, about 2560.

The probability of this explanation is enhanced by the fact that the maximum for bodies having a strong selective reflection in the infra-red, is always considerably higher in the spectrum than for oxide of iron or lampblack at the same temperature. The order of the substances which have been mentioned, for any

temperature which is the same for all, is: platinum, bright carbon (graphite), oxide of copper, oxide of iron, lampblacked platinum or oxide; so that the maximum for bright platinum always has the smallest wave-length.

Second; according to my recent investigations on the dispersion of my spectrum, the smaller wave-lengths are to be taken a little smaller than the values determined from earlier measurements. Although the amount of the correction is exceedingly small (about $\frac{1}{14}$ of the width of the bolometer strip at 2μ), its effect is nevertheless perceptibly to diminish the wave-lengths λ_{max} of the curves for high temperatures; the product $\lambda_{max} \times$ abs. temp. is likewise diminished, and hence the relation holds more nearly than before. I have not applied this correction, as the measures for determining the dispersion are not yet completed. In comparison with that first mentioned due to selective reflection, its effect is almost negligible.

Third; the effect of the selective absorption of the lampblacked bolometer strip is to be noticed. According to all that we know of the absorption of lampblack, from the researches of Ångström, its effect would be similar to that of the cause first mentioned, *i. e.*, it would tend to made the product $\lambda_{max} \times$ abs. temp. too small for the greater wave-lengths and low temperatures.

Finally, the zero point of my curves is not the absolute zero, but about 290° on the absolute scale; it is the temperature of a screen placed before the slit, the spectrum of which lies in the greater wave-lengths. The longer waves in my curves would therefore receive proportionally greater ordinates if the curves were referred to the absolute zero of temperature.

These are the principal causes of the fact that the product $\lambda_{max} \times$ abs. temp. as furnished by observation is too small for long waves and low temperatures. If we regard them as furnishing a satisfactory explanation, we may say, with some degree of probability, that *the wave-length of the maximum of energy in the spectrum of an absolutely black body is inversely proportional to the absolute temperature;* or, *the vibration-frequency of the waves*

chiefly radiated by the molecules of the body is proportional to the absolute temperature. The law must hold for any body incapable of reflection,—gaseous, fluid or solid,—in so far as the molecular vibrations are concerned from which Kirchhoff's law is deduced For example, an infinitely thick layer of a gas which absorbs all waves to some extent may be regarded as an absolutely black body.

If we choose to assume that the absolute scale of temperature is still unknown, we may define it by means of the relation given above. Its zero point would be defined as the temperature at which the vibration-frequency of the molecules of an absolutely black body is equal to zero. The zero point which is deduced from these considerations is nearly the same as that deduced from the laws of gases and the mechanical theory of heat.

I will not enter into further conclusions which may be drawn from this law with respect to its bearing on physical questions. It deserves to be mentioned, however, that the theory of Kövesligethy leads to the two laws which here have no other than an empirical basis.

If the quantitative result of my investigations is provisionally assumed to be

$$\lambda_{max} \times \text{abs. temp.} = 2700,$$

Langley's value $0^{\mu}.5$ for the position of maximum energy in the normal solar spectrum gives

$$\text{solar temperature} = \frac{2700}{0.5} \text{ degrees on the absolute scale} = 5130^{\circ}\text{C.};$$

that is, the Sun gives an energy spectrum which is the same as that of an absolutely black body at 5130°C.; and this would be its temperature if its light were entirely a consequence of its heated condition and if its surface possessed no selective reflection. The latter condition would be fulfilled if the Sun is a gaseous body.

In my opinion the least accurate, because most difficult, part of the investigation leading to this result, is the determination of the wave-length of the maximum in the solar energy curve

when freed from the effects of absorption and reduced to the normal scale. It is to be hoped that a more exact determination of this value may be made.

A characteristic fact in the history of the measurement of very high temperatures is, that all the high values tend to be reduced by improved methods. It is especially noticeable in the case of the temperature of the Sun, for while Rosetti's value was 10,000°, and even higher values were computed by earlier observers, those which have been obtained in recent times are materially smaller. Messrs. W. E. Wilson and P. L. Gray,[1] following Rosetti's method, have quite lately obtained a solar temperature of 6200°C. Not only the course of the historical development of the question, but the experimental basis of these and my own researches seems to point to the conclusion that the lower values are the more nearly correct.

HANNOVER, TECHN. HOCHSCHULE,
June, 1895.

[1] *Phil. Trans.*, 1894, p. 361.

ON THE EFFECT OF PRESSURE OF THE SURROUNDING GAS ON THE TEMPERATURE OF THE CRATER OF AN ELECTRIC ARC LIGHT.[1]

By W. E. Wilson.

Of late years it has often been assumed that the temperature of the crater forming the positive pole of the electric arc is that of the boiling of carbon. The most modern determinations give this point as about 3300°–3500° C.

Solar physicists have thought that the photosphere of the Sun consists of a layer of clouds formed of particles of solid carbon. As the temperature of these clouds is certainly not below 8000° C., it seems very difficult to explain how carbon can be boiling in the arc at 3500° and yet remain in the solid form in the Sun at 8000°. Pressure in the solar atmosphere seemed to be the most likely cause of this, and yet, from other physical reasons, this seemed not probable.

In order to investigate whether increased pressure in the gas surrounding an electric arc would raise the temperature of the crater, I had an apparatus made by the Cambridge Instrument Company. It consists of a strong cast-iron box, which was tested by hydraulic pressure to 2000 pounds per square inch. The negative carbon was kept in position against a copper ring by a spiral spring behind it. The positive carbon was hand-fed by a friction roller, which was moved by a handle outside the box. A steel tube was screwed into the box at such an angle that, by looking down it, we could see well into the crater of the positive pole. The end of this tube is closed by a glass lens, which formed an image of the crater at a distance of 80^{cm}.

A Boys' radio-micrometer, with its aperture reduced to about 2^{mm} diameter, was so placed on the pier in the laboratory that the image of the crater fell on its small aperture. The instrument thus gave deflections proportional to the radiation coming

[1] Read before the Royal Society.

from the crater. The current was supplied from a battery of accumulators, giving an E. M. F. of 110 volts. Suitable resistances of platinoid wire were put in the circuit, so that the current could be varied from 40 to 10 ampères. An ammeter was also in circuit, and the poles of the arc were connected to a voltmeter.

The gas used was nitrogen, and the pressure was got by connecting the box by a copper pipe with the valve of a 20-foot steel cylinder filled with the gas at a pressure of 120 atmospheres. A T-joint on the copper pipe was connected with a Bourdon pressure-gauge, which showed the pressure in the box at any moment.

The method of experimenting was first to start the arc with the pressure in the box at that of the atmosphere. The image of the brightest part of the crater was thrown on the aperture of the radio-micrometer, and a series of observations taken of the deflections of the instrument. The pressure was then gradually increased and the maximum deflections observed. As the pressure rises the resistance of the arc increases, and, in order to keep the same current flowing, the resistance in the circuit was reduced. It soon became evident that, even with moderate pressures of about 5 atmospheres, the temperature of the crater had fallen. This was not only shown by the reduction in the deflections of the radio-micrometer, but also by the fall in brilliancy of the image of the crater to the eye. The pressure was then increased to about 20 atmospheres, and the brilliancy of the crater fell to a dull red color. These experiments were repeated several times and always with the same results.

I then tried the effect of reducing the pressure in the box by means of an air-pump, but as some of the glands in the box were only intended for an internal pressure, I found it impossible to get a good vacuum; yet by keeping the pump at work, and thus getting a moderate vacuum, I found the radiation of the crater to be much greater than at the atmospheric pressure.

The temperature of the crater seemed very sensitive to any sudden diminution of pressure in the gas. If the blow-off valve was suddenly opened, the brilliancy of the crater fell so much that it became nearly invisible. When the box was being

exhausted by the air-pump, although the temperature of the crater was rising as the vacuum improved, yet at each stroke of the pump the eye could see a distinct falling off of brilliancy in the image.

It was thought that the diminution of brilliancy might be due to smoke inside the box, but on looking through the window everything was seen sharply defined, also the gas as it issued from the blow-off was perfectly clear. The arc was also kept burning for some time in the box at the atmospheric pressure, but the image remained quite clear, and the inside of the box seemed quite free of smoke.

From these experiments it would seem as if the temperature of the crater, like that of a filament in an incandescent lamp, depends on how much it is cooled by the surrounding atmosphere, and not on its being the temperature at which the vapor of carbon has the same pressure as the surrounding atmosphere. That carbon volatilizes in some form at comparatively low temperatures seems likely, from the way in which the carbon of incandescent lamp filaments is transferred to the glass. The pressure of the vapor of carbon in the arc may consequently be very small, and further it would seem that the supposition of high pressures in the solar photosphere, which has been referred to in the beginning of this paper, is not borne out by these experiments, and that carbon may exist there in the solid form at very high temperatures although the pressures are comparatively low.

The experiments on high pressures were conducted on several occasions. On the last occasion, in addition to repeated former experiments, the experiments on reduced pressures were performed, and I then had the great advantage of the presence, advice, and assistance of my friends Professor Minchin and Professor G. F. Fitzgerald. The later series of experiments entirely confirmed my former ones.

A CONTRIBUTION TO THE THEORY OF RADIATION.[1]

By G. JAUMANN.

IN the following article it is shown (1) that the vibrations which are the source of radiation of a luminous body are demonstrably and measurably *damped*, and (2) that they are not excited by fortuitous impulses, but by the continuous influence of a cause which is periodic in its action.

1. DAMPING OF RADIATION AND CONTINUOUS SPECTRA.

A continuous spectrum is at present regarded as the limiting case of a line spectrum in which the number of lines is infinitely great. According to Newton, an infinite number of different rays are present in white light, and, in fact, white light can be produced by again combining these rays.

Now it seems improbable that the most satisfactory conception of the process of emission is obtained by supposing that a white-hot body gives out an infinite number of vibrations. Such a complicated representation has perhaps been arrived at because the nature of the process is such that the emitted light cannot well be represented as a sum of periodic vibrations. In order to understand what takes place in *dispersion*, on the other hand, Newton's conception is the best.

The different colors of a spectrum are regarded as *incoherent*. This is a condition of things which it would be difficult to prove directly. The reverse condition, however, in case it is found to be compatible with the facts, can be proved indirectly. If the rays of a continuous spectrum are coherent, they can be compounded. The result of this integration is that the radiated light-wave can be represented as a simple, even if *not a periodic*, function. If, now, the emission of the non-periodic wave so resulting is comprehensible from other points of view, we might

[1] *Zur Kenntniss des Ablaufes der Lichtemission;* von G. Jaumann. Translated from *Annalen der Physik und Chemie*, **53**, 832.

hope to reach some conclusion as to the nature of radiation, and at the same time be able to admit the hypothesis *that the different rays of a continuous spectrum are coherent.*

The intensity of the rays of a continuous spectrum is a function of the period of vibration.[1] If we let da represent the amplitude of such a vibration, *i. e.*, the square root of the intensity of rays whose periods fall between u and $(u + du)$, we have the relation

$$da = f(u)\,du.$$

The displacement at time t is represented by

$$da \sin ut = f(u)\,du \sin ut.$$

If all the vibrations are coherent and have similar phases, they can be compounded into a resultant vibration, which is given by the integral

$$\phi(t) = \int_0^\infty f(u) \sin ut\,du, \tag{1}$$

which is to be extended throughout the entire spectrum. $\phi(t)$ represents the true emission.

In this direction, however, no further progress can be made. There are no experimental determinations of $f(u)$, as only a very few volumetric measurements have been made, and these not in continuous spectra which can be regarded as simple.

It is necessary to take the opposite course, and to start from an assumption as to the nature of emission, *i. e.*, of the function $\phi(t)$. Now, the most natural supposition is that the emission takes place under conditions of strong damping.

The radiating vibrations will then, like all damped vibrations, follow the law

$$\left.\begin{aligned} \phi(t) &= Ae^{-\kappa t} \sin pt, \\ p^2 &= u_1^2 - \kappa^2, \end{aligned}\right\} \tag{2}$$

in which κ is the constant of damping, and u the period of the undamped vibration.

This vibration $\phi(t)$ continues from $t = 0$ to $t = \infty$, before it is extinguished. Such a vibration cannot be represented by

[1] Period of vibration here signifies the quotient $\frac{2\pi}{\tau}$, in which τ is the time during which the vibration continues.

Fourier's theorem as a discrete, even if infinite, series of sine vibrations, but only as a *continuum* of such vibrations. The distribution of amplitudes in such a continuous spectrum is found by means of the Fourier integral

$$\phi(t) = \frac{2}{\pi}\int_0^\infty \sin tu\, du \int_0^\infty \phi(t) \sin ut\, dt.$$

It is here assumed that the elementary vibrations have the same phase as the resultant vibration, an assumption which is rendered necessary by the requirement that the intensity must vanish in the infra-red and ultra-violet portions of the spectrum for which $u = 0$ and $u = \infty$ respectively.

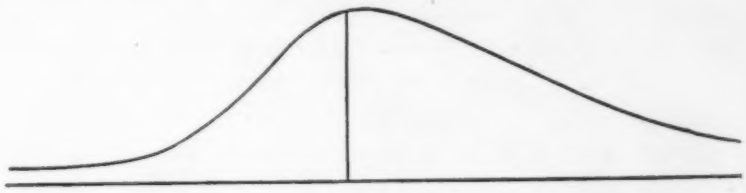


FIG. 1

By comparison of the Fourier integral with equation (1) it follows that the required distribution of amplitudes is represented by

$$f(u) = \frac{2}{\pi}\int_0^\infty \phi(t) \sin ut\, dt.$$

Finally, introducing the assumption as to the nature of the function $\phi(t)$ which is stated in equation (2), and performing the integration, we obtain

$$f(u) = \frac{4}{\pi} A\kappa p \frac{u}{(\kappa^2 + p^2 + u^2)^2 - 4p^2u^2}. \tag{3}$$

The period V, for which $f(u)$ is a maximum, is determined by

$$V^4 - \tfrac{2}{3}(p^2 - \kappa^2)V^2 - \tfrac{1}{3}(p^2 + \kappa^2)^2 = 0.$$

There is, consequently, only one maximum of $f(u)$ between the limits of integration $u = 0$ and $u = \infty$. This maximum always lies between $u_1 = 1/\sqrt{p^2 + \kappa^2}$ and p, and approaches u_1 when the damping is diminished (at the beginning of luminosity). These relations are represented graphically in Fig. 1.

When the damping is not quite aperiodic, the displacement $(u_1 - V)$ of the maximum from the undamped period u_1 is always an imperceptibly small quantity of the second order.

The transition from an undamped sine vibration to this analysis of a damped vibration corresponds so closely to the transition from a sharp to a broadened spectral line that the following assumption is justifiable:

The broadening of spectral lines is explained as the result of damping of the vibrations to which the emission of light is due.

A broadened line is essentially a continuous spectrum. The spectrum of most white-hot bodies may be regarded as made up of a number of overlapping broadened lines.[1]

The radiation of light by a solid or liquid incandescent body or a dense gas takes place, therefore, under the influence of a damping action on the molecular vibrations. The value of the constant of damping κ can be given with the same degree of certainty as that which attaches to our knowledge of the distribution of intensity in a broadened line.

Suppose, for example, that the constant of damping is

[1] Among previous explanations of the broadening of spectral lines may be mentioned the following:

Zöllner (*Pogg. Ann.*, 1871) assumes that gases always yield continuous spectra, the intensity of which is, however, so small as to be imperceptible, except where the characteristic bright lines occur. The continuous spectrum becomes noticeable under increased pressure. This view is not incorrect, but the fundamental idea is unfruitful.

Lippich (*Pogg. Ann.*, 1870), from the standpoint of the kinetic theory of gases, connects broadening of the lines with deviation from Mariotte's law.

Kayser (*Winkelmann's Handbuch der Physik*, 1894) explains the broadening, from the standpoint of the molecular theory, as the secondary effect of collisions among the molecules, which occur more frequently when the density of the gas is increased.

Lockyer concludes from the broadening of the spectral lines that dissociation of the elements must take place.

Ebert (*Wied. Ann.*, 1889) explains the broadening on Doppler's principle, as the result of the motion of vibrating molecules in the line of sight.

The view has also been expressed that the broadening of doublets is analogous to the production of combination tones in acoustics, and is due to the great amplitude of the vibrations which cause the emission of light.

So far as I know, Fourier's theorem has only been applied to spectroscopic problems by Stoney, but without results of any value, as he merely arrived at the conjecture that harmonic vibrations must be found in the spectrum, which is not the case.

required for the magnesium line λ 2852. Under certain circumstances this line widens so greatly that, even as far as the wavelength 2950, the intensity becomes a quarter as great as the maximum, *i. e.*, the amplitude $f(u)$ is half that of the maximum amplitude $f(V)$. With these values we find from equation (3)

$$\kappa = 10^{13} \times 19 \text{ sec}^{-1}.$$

Hence the amplitude of the vibration falls off in only five oscillations in the ratio of e: 1.

A still more extreme case of damping is shown by the hydrogen lines under high pressure. In general, however, the observed

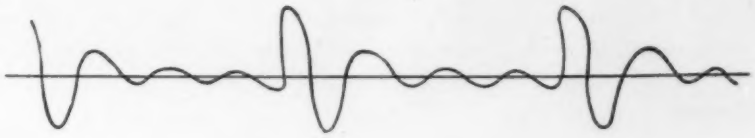


FIG. 2

broadening of spectral lines is very small. The amplitude falls off in the ratio of e: 1 only after from fifty to 100 oscillations.

II. PERIOD OF EXCITATION. BANDS OR SERIES OF LINES.

If the radiating vibrations are damped, and the flow of light is continuous, some cause must be present which from time to time excites these vibrations anew. Such excitations might occur fortuitously at irregular intervals, or periodically.

We will make the latter assumption and see what consequences it leads to.

If the excitement is periodic, the process of emission, although subject to damping, acquires an additional period; namely, that of the exciting impulse. Fig. 2 represents such a vibration.

Now, according to Fourier's theorem, the vibration is, as a periodic function, resolved by the prism into a sum of discrete sine vibrations, whose periods are whole multiples of the period of the function,—which is, in this case, the period of the exciting impulse.

The periodically excited radiation has, therefore, a line spectrum. The vibration-frequencies of these lines represent whole multiples of the excitation-frequency.

The excitation-frequency per second is in any case much smaller than the frequency of the radiating vibration, since many of the damped vibrations pass away before another exciting impulse follows. The multiples of the excitation-frequencies are, therefore, also very close together, and hence the spectrum is crossed by a great number of fine equidistant lines, the intervals depending upon the vibration-frequencies.

The difference between the vibration-frequencies of two of these lines is equal to the excitation-frequencies per second.

Nothing is said in the above statement with regard to the strength of these lines. It follows from the convergence of the Fourier theorem that they must become weaker and weaker as they approach the extreme ultra-violet. In the infra-red, however, they are not necessarily stronger than in the visible spectrum; they may be weaker there, or they may entirely disappear. Further, they need not all appear, even in the region of greatest strength, for certain lines may fail in accordance with some law which we may well suppose to exist, the amplitudes of the missing vibrations becoming zero in accordance with the special nature of the periodic function.

It may easily be seen how this distribution of amplitudes is determined in any given case. The longer the interval between the exciting impulses, the more finely will the spectrum be ruled, and if the interval is so long that the emitted vibrations have time to nearly die away, the spectrum will be very nearly continuous, and the distribution of intensity will follow the law stated in the preceding section of this paper.

With greater frequency of excitement the spectrum will be discontinuous, but, as a whole, it will exhibit the same distribution of intensity. We have in this case *a spectral band, or line series.*

The vibration-frequencies n of all the lines which constitute a band are, according to Deslandres,[1] determined by the law

$$n = a \pm b\kappa^2,$$

[1] *C. R.*, 1889, 1890.

in which a and b are constants, and κ represents the whole numbers. The difference between any two vibration-frequencies is a whole multiple of the constant b, which is, therefore, the vibration-frequency of the exciting impulse. *The entire band, which is often made up of hundreds of lines, is emitted by a single, damped, periodically excited sine vibration.*

For example, Deslandres represents the sixty-three lines in the band $\lambda 3914.6 - 3827.4$, which is found in the spark spectrum of nitrogen at normal pressure, by the formula

$$\tfrac{1}{3}\, 10^{-12}\, n = 255.45 + 0.001534\,(\kappa - 1)^2.$$

In this case there are about 1½ (more exactly, 1.534) exciting impulses during 255450 radiated vibrations.

A band at $\lambda 3891.5 - 4033.8$ in the spectrum of an illuminating gas flame, in which twenty lines appear, Deslandres represents by

$$\tfrac{1}{3}\, 10^{-13}\, n = 257.04 - 0.02078\,(\kappa - 1)^2.$$

Here, in nearly the same number of emitted vibrations (namely, 257040), there are no less than 20.78 exciting impulses.

From the distribution of intensity in such a band, the damping of the vibration which produces the emission can also be estimated, as was shown in the preceding section. The line No. 11, $\lambda = 3936.4$, of the above band is the strongest. The intensity falls off on both sides. At line No. 5, $\lambda = 3902.4$, it is only about one-fourth that of the maximum. The constant of damping, computed from these data, is

$$\kappa = 10^{13} \times 3.9\ \text{sec}^{-1}.$$

Hence the illuminating gas gives out a vibration whose wave-length is 0.000394^{mm}, which is so damped that its amplitude falls off in the ratio $e:1$ after twenty-one vibrations, and which after 12360 vibrations is again excited.

III. DEVIATIONS FROM SYMMETRICAL DISTRIBUTION OF INTENSITY, AND FROM DESLANDRES' LAW.

The distribution of intensity in bands, less frequently in widened lines, is under some circumstances one-sided. This

appearance I connect provisionally with the phenomena of doublets and triplets, which are directly observable. They result from simultaneous vibrations with a given relation of amplitude. If both widen, a one-sided distribution of intensity is produced, as shown in Fig. 3, in which the distribution of intensity of the components is represented by dotted lines, that of the result by the unbroken curve.

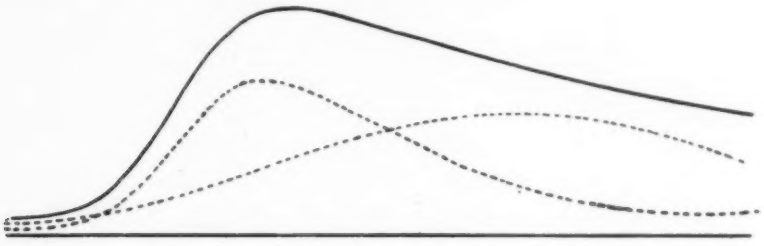


FIG. 3

Balmer[1] represents the lines of a series more accurately by

$$n = a + b\kappa^{-2},$$

while a still better agreement with observation is obtained by Kayser and Runge,[2] by means of the formula

$$n = a + b\kappa^{-2} + c\kappa^{-4}.$$

To a first approximation this formula agrees with Deslandres', but the numbering must begin at the other end of the series.

Thus Deslandres' formula is not rigorously exact. It follows that, while the exciting impulse can be regarded as periodic to within a first approximation, it is not completely so. But since there must be a very great regularity in the periods of excitement, in order to produce the spacing of lines according to the law of Kayser and Runge, I am induced to believe that the excitation is not produced by periodical impulses, but by the continuous influence of another vibration, which is itself damped, and which is, therefore, very nearly, but not quite, periodic.

As an illustration, let a tuning-fork be taken, and let it be set in vibration by a violin-bow, which is not, however, drawn uni-

[1] *Wied. Ann.*, 1885.

[2] *Abh. der Berl. Akad.*, 1890, 1891, 1892.

formly across the fork, but with a damped and sinuous motion.

If the exciting vibration is damped, it itself requires an exciting cause, and this stimulus of the second order may either be of a fortuitous nature, or it may again be periodic. In the latter case a series of bands, instead of a series of lines, would result, such as we find, for example, in the group of bands at λ 5000 — 2800 in the spectrum of nitrogen.

SOLAR OBSERVATIONS MADE AT THE ROYAL OBSERVATORY OF THE ROMAN COLLEGE: JANUARY–JUNE, 1895.

By P. TACCHINI.

I SEND you the results of the solar observations made at our observatory during the first six months of the year 1895. They are tabulated as follows for the spots and faculæ:

1895	Number of days of Observ aion	Relative Frequency		Relative Areas		Number of Spot Groups per day
		of Spots	of days without Spots	of Spots	of Faculæ	
January	17	14.30	0	54.1	65.6	3.8
February	14	17.86	0	61.5	53.9	5.2
March	26	18.73	0	67.3	74.6	4.3
April	22	22.50	0	86.5	120.9	5.7
May	.....	17.80	0	57.4	55.0	4.7
June	27	21.22	0	60.0	57.4	4.7

The decrease in the phenomena of Sun-spots which was established in the closing months of 1894 has been found also in this series of 1895, with a secondary minimum very marked in January. The mean number of groups has remained nearly the same as in the last quarter of 1894, so that we can consider the phenomenon of spots as stationary from October 1894 to date; we are then, as in accordance with the rule, approaching very slowly the true minimum.

For the prominences we have reached the following results:

1895	Prominences			
	Number of days of Observation	Mean Number	Mean Height	Mean Extent
January	10	2.60	31″.9	2°.4
February	17	5.25	43 .3	2 .2
March	18	6.89	46 .0	1 .9
April	18	7.11	41 .1	1 .8
May	17	7.94	40 .0	1 .7
June	25	6.96	37 .2	1 .6

It is true that the season has not been favorable, especially at the beginning of the year, but I think that the coincidence of the secondary minimum of spots and prominences in the month of January can be admitted. After January we have a feeble increase in the phenomena of the chromosphere.

FIRST QUARTER, 1895.

Latitudes	Prominences		Faculæ.		Spots	
90° +80°	0.000					
80 +70	0.000					
70 +60	0.005					
60 +50	0.009					
50 +40	0.009	0.505	0.000			
40 +30	0.054		0.006			
30 +20	0.116		0.055	0.423	0.056	
20 +10	0.138		0.178		0.296	0.465
10 . 0	0.176		0.184		0.113	
0 −10	0.089		0.184		0.183	
10 −20	0.125		0.221		0.253	0.535
20 −30	0.111		0.123	0.577	0.099	
30 −40	0.049		0.043			
40 −50	0.094	0.495	0.006			
50 −60	0.022					
60 −70	0.000					
70 −80	0.005					
80 −90	0.000					

SECOND QUARTER, 1895.

Latitudes.	Prominences		Faculæ		Spots	
90° +80°	0.000					
80 +70	0.000					
70 +60	0.002					
60 +50	0.020					
50 +40	0.055	0.581				
40 +30	0.100		0.018			
30 +20	0.148		0.084	0.458	0.080	
20 +10	0.128		0.205		0.241	0.505
10 . 0	0.128		0.151		0.184	
0 −10	0.084		0.151		0.115	
10 −20	0.082		0.218	0.542	0.300	0.495
20 −30	0.110		0.151		0.080	
30 −40	0.068		0.022			
40 −50	0.053	0.419				
50 −60	0.015					
60 −70	0.000					
70 −80	0.000					
80 −90	0.007					

As to the distribution in latitude of the solar phenomena I have calculated according to quarters, and have obtained the above results by zones in the two hemispheres.

During the first quarter the prominences show almost the same frequency north and south of the equator, although in the second they are more numerous in the northern zones, and probably we are already in the presence of a greater northern activity.

The frequency of faculæ has continued greater in the southern zones, and the maximum frequency is always in the zone $-10° -20°$. The prominences have been always in considerable number in the large zone $0° \pm 50°$, and very rare between $\pm 50° \pm 90°$.

The spots, like the faculæ, present their maximum in the zone $-10° -20°$, but they do not extend beyond the parallels $\pm 30°$.

As to the general distribution of groups there is already an indication of the transferring of the locality of greater activity from the southern to the northern latitudes.

Metallic eruptions have not been observed, nor phenomena in the chromosphere worthy of note in the vicinity of spots.

ROME, September 3, 1895.

THE SPECTRUM OF HELIUM.[1]

By W. CROOKES.

IN the *Chemical News* for March 29 last (**71**, 151), I published the results of measurements of the wave-lengths of the more prominent lines seen in the spectrum of the gas from clèveite, now identified with helium. The gas had been given to me by the discoverer, Professor Ramsay; and being from the first batch prepared, it contained other gases as impurities, such as nitrogen and aqueous vapor, both of which gave spectra interfering with the purity of the true helium spectrum. I have since, thanks to the kindness of Professors Ramsay and J. Norman Lockyer, had an opportunity of examining samples of helium from different minerals and of considerable purity as far as known contamination is concerned. These samples of gas were sealed in tubes of various kinds and exhausted to the most luminous point for spectrum observations. In most cases no internal electrodes were used, but the rarefied gas was illuminated solely by induction, metallic terminals being attached to the outside of the tube.[2] For photographic purposes a quartz window was attached to the end of the tube, so that the spectrum of the gas could be taken "end on."

My examinations have chiefly been made on five samples of gas.

(1) A sample from Professor Ramsay in March last. Prepared from clèveite.

(2) A sample from Professor Ramsay in May last. Prepared from a specimen of uraninite sent to him by Professor Hillebrand. Gas obtained by means of sulphuric acid; purified by sparking.

(3) A sample from Professor Ramsay in June last. Prepared from bröggerite.

[1] From the *Chemical News*, August 23.

[2] *Journal of the Institution of Electrical Engineers*, part 91, **20**, Inaugural Address by the President, William Crookes, F.R.S., January 15, 1891.

(4) A sample from Professor Lockyer in July last. Prepared by a process of fractional distillation from a sample of bröggerite sent by Professor Brögger.

(5) A sample of gas from Professor Ramsay, "Helium Purissimum." This was obtained from mixed sources, and had been purified to the highest possible point.

In the following table the first four samples of gas will be called: (1) "Clèveite, R.;" (2) "Uraninite, R.;" (3) "Bröggerite, R.;" and (4) "Bröggerite, L." Only the strongest of the lines, and those about which I have no doubt, are given. The wave-lengths are on Rowland's scale.

The photographs were taken on plates bent to the proper curvature for bringing the whole spectrum in accurate focus at the same time. The spectrum given by a spark between an alloy of equal atoms of mercury, cadmium, zinc and tin was photographed at the same time on the plate, partially overlapping the helium spectrum; suitable lines of these metals were used as standards. The measurements were taken by means of a special micrometer reading approximately to the $\frac{1}{100000}$ inch, and with accuracy to the $\frac{1}{100000}$ of an inch. The calculations were performed according to Sir George Stokes' formula, supplemented by an additional formula kindly supplied by Sir George Stokes, giving a correction to be applied to the approximate wave-lengths given by the first formula, and greatly increasing the accuracy of the results.

Wave-length.	Intensity.	
7065.5	5	A red line, seen in all the samples of gas. Young gives a chromospheric line at 7065.5.
6678.1	8	A red line, seen in all the samples of gas. Thalén gives a line at 6677, and Lockyer at 6678. Young gives a chromospheric line at 6678.3.
5876.0	30	The characteristic yellow line of helium, seen in all the samples of gas. Thalén makes it 5875.9, and Rowland 5875.98. Young gives a chromospheric line at 5876.
5062.15	3	
5047.1	5	A yellow-green line, only seen in "Helium Puriss." and in "Bröggerite, R," and "L." Thalén gives the wave-length as 5048.

Wave-length.	Intensity.	
5015.9	7	A green line seen in all the sample of gas. Thalén gives the wave-length 5016. Young gives a chromospheric line at 5015.9.
4931.9	3	
4922.6	10	A green line, seen in all the samples of gas. Thalén gives the wave-length 4922. Young gives a chromospheric line at 4922.3.
4870.6	7	A green line, only seen in "Uraninite, R." Young gives a chromospheric line at 4870.4.
4847.3	7	A green line, only seen in "Uraninite, R." Young gives a chromospheric line at 4848.7.
4805.6	9	A green line, only seen in "Uraninite, R." Young gives a chromospheric line at 4805.25.
4764.4	2	There is a hydrogen line at 4764.0.
4735.1	10	A very strong greenish blue line, only seen in "Uraninite, R."
4713.4	9	A blue line, seen in all the samples of gas. Thalén's measurement is 4713.5. Young gives a chromospheric line at 4713.4.
4658.5	8	A blue line, only seen in "Uraninite, R."
4579.1	3	A faint blue line, seen in "Uraninite, R." Lockyer gives a line at 4580, from certain minerals. I can see no traces of it in the gas from Bröggerite. A hydrogen line occurs at 4580.1.
4559.4	2	Young gives a chromospheric line at 4558.9.
4544.1	5	
4520.9	3	A faint blue line, seen in "Uraninite, R." Lockyer gives a line at 4522, seen in the gas from some minerals. Young gives a chromospheric line at 4522.9. It is absent in the gas from Bröggerite.
4511.4	5	A blue line, seen in "Uraninite, K," but not in the others. It is coincident with the strong head of a carbon band in CO_2 and Cy spectrum.
4497.8	2	There is a hydrogen line at 4498.75.
4471.5	10	A very strong blue line, having a fainter line on each side, forming a close triplet. It is a prominent line in all the samples of gas examined. Young gives the wave-length 4471.8 for a line in the chromosphere, and Lockyer gives 4471 for a line in gas from Bröggerite.
4435.7	9	Seen in "Helium Puriss."
4437.1	1	Young gives a chromospheric line at 4437.2.

Wave-length.	Intensity.	
4428.1	10	These two lines form a close pair. I can only see them in "Uraninite, R." No trace of them can be seen in the gases from other sources. Young gives chromospheric lines at 4426.6 and 4425.6.
4424.0	10	
4399.0	10	A strong line, only seen in "Uraninite, R." Absent in the gas from the other sources. Lockyer gives a line at 4398 in gas from certain minerals. Young gives a chromospheric line at 4398.9.
4386.3	6	Seen in all the samples of gas. Young gives a chromospheric line at 4385.4.
4378.8	8	These two lines form a pair seen in "Uraninite, R," but entirely absent in the others.
4371.0	8	
4348.4	10	Seen in "Uraninite, R." Lockyer finds a line at 4347 in the gas from certain minerals.
4333.9	10	Probably a very close double line. Seen in "Uraninite, R," Clèveite. R." Not seen in the other samples. Lockyer gives a line in the gas from certain minerals at 4338.
4298.7	6	Only seen in "Uraninite, R." Young gives a chromospheric line at 4298.5.
4281.3	5	Only seen in "Uraninite, R."
4271.0	5	Only seen in "Uraninite, R." The strong head of a nitrogen band occurs close to this line.
4258.8	7	Seen in all the samples of gas.
4227.1	5	Only seen in "Uraninite, R." Young gives a chromospheric line at 4226.89.
4198.6	9	These three lines form a prominent group in "Uraninite, R," they are very faint in "Clèveite, R," and in "Bröggerite, L," but are not seen in "Bröggerite, R."
4189.9	9	
4181.5	9	
4178.1	1	An extremely faint line. Lockyer gives a line at 4177, seen in the gas from certain minerals, and Young gives a chromospheric line at 4179.5
4169.4	6	Seen in "Helium Puriss."
4157.6	8	A strong line in "Uraninite, R," very faint in "Bröggerite, R," and "L," not seen in "Clèveite, R."
4143.9	7	Strong in "Clèveite, R," in "Helium Puriss.," and in "Bröggerite, L." It is faint in "Uraninite, R." and not seen in "Bröggerite, R." Lockyer gives a line at 4145 in gas from certain minerals.
4121.3	7	Present in all the gases except "Clèveite, R."
4044.3	9	Present in "Uraninite, R," and "Clèveite, R." Absent in the others.

Wave-length.	Intensity.	
4026.1	10	These lines form a very close pair, seen in all the samples of gas, except "Bröggerite, R." Lockyer finds a line in Bröggerite gas at 4026.5.
4024.15	6	
4012.9	7	Seen in all the samples of gas.
4009.2	7	Seen in "Helium Puriss."
3964.8	10	The center line of a dense triplet. Only seen in "Clèveite, R," in "Helium Puriss.," and "Bröggerite, L." Hale gives a chromospheric line at 3964.
3962.3	4	Seen in all the samples of gas.
3948.2	10	Very strong in "Uraninite, R," very faint in "Clèveite, R," and not seen in the others. Lockyer finds a line in gas from Bröggerite at 3947. There is an eclipse line at the same wave-length.
3925.8	2	Seen in "Helium Puriss."
3917.0	2	Seen in "Helium Puriss."
3913.2	4	Only seen in "Uraninite, R," and "Helium Puriss." Hale gives a chromospheric line at 3913.5.
3890.5	9	A very strong triplet, seen in all the samples of gas. Lockyer finds a line having a wave-length 3889 in gas from Bröggerite. Hale gives a chromospheric line at 3888.73. There is a strong hydrogen line at 3889.15.
3888.5	10	
3885.9	9	
3874.6	6	Only seen in "Uraninite, R."
3867.7	8	Seen in "Helium Puriss."
3819.4	10	Seen in all the samples of gas. Deslandres gives a chromospheric line at 3819.8.
3800.6	4	Seen in "Helium Puriss."
3732.5	5	Seen in "Helium Puriss." Hale gives a chromospheric line at 3733.3.
3705.4	6	Seen in all the samples of gas. Deslandres gives a chromospheric line at 3705.9.
3642.0	8	Only seen in "Uraninite R."
3633.3	8	Seen in "Helium Puriss."
3627.8	5	Only seen in "Uraninite, R."
3613.7	9	Seen in "Helium Puriss."
3587.0	5	Seen in "Helium Puriss."
3447.8	8	Seen in "Helium Puriss."
3353.8	5	Seen in "Helium Puriss."
3247.5	2	Seen in "Helium Puriss."
3187.3	10	The center line of a close triplet. Very faint in "Clèveite, R," and "Uraninite, R." and strong in "Helium Puriss.," and in "Bröggerite, L." It is not seen in "Bröggerite, R."

Wave-length.	Intensity.	
2944.9	8	A prominent line, only seen in "Helium Puriss." and in "Bröggerite, L."
2536.5	8	Seen in "Helium Puriss." A mercury line occurs at 2536.72.
2479.1	4	Seen in "Helium Puriss."
2446.4	2	Seen in "Helium Puriss."
2419.8	2	Seen in "Helium Puriss."

Some of the more refrangible lines may possibly be due to the presence of a carbon compound with the helium. To photograph them, a long exposure, extending over several hours, is necessary. The quartz window has to be cemented to the glass with an organic cement, and the long-continued action of the powerful induction current on the organic matter decomposes it, and fills the more refrangible end of the spectrum with lines and bands in which some of the flutings of hydrocarbon, cyanogen, and carbonic anhydride are to be distinguished.

There is a great difference in the relative intensities of the same lines in the gas from different minerals. Besides the case mentioned by Professor Kayser of the yellow and green lines, 5876 and 5016, which vary in strength to such a degree as to render it highly probable that they represent two different elements, I have found many similar cases of lines which are relatively faint or absent in gas from one source and strong in that from another source.

Noticing only the strongest lines, which I have called "Intensity 10," "9," or "8," and taking no account of them when present in traces in other minerals, the following appear to be special to the gas from uraninite:

4735.1
4658.5
4428.1
4424.0
4399.0
4378.8
4371.0
4348.4
4198.6
4189.9

4181.5
4157.6
3948.2
3642.0

The following strong lines are present in all the samples of gas:

7065.5
6678.1
5876.0
5015.9
4922.6
4713.4
4471.5
4386.3
4258.8
4012.9
3962.3
3890.5
3888.5
3885.9
3819.4
3705.4

The distribution assigned to some of the lines in the above tables is subject to correction. The intensities are deduced from an examination of photographs, taken with very varied exposures; some having been exposed long enough to bring out the fainter lines, and some a short time to give details of structure in the stronger lines. Unless all the photographs have been exposed for the same time, there is a liability of the relative intensities of lines in one picture not being the same as those in another picture. Judgment is needed in deciding whether a line is to have an intensity of 7 or 8 assigned to it; and as in the tables I have not included lines below intensity 8, it might happen that another series of photographs with independent measurements of intensities would in some degree alter the above arrangement.

In the following table I have given a list of lines which are probably identical with lines observed in the chromosphere and prominences:

Wave-lengths observed of helium	Intensities	Wave-lengths of chromospheric lines,[1] Rowland's scale	Wave-lengths observed of helium	Intensities	Wave-lengths of chromospheric lines,[1] Rowland's scale
7065.5	10	7065.5	4424.0	10	4425.6
6678.1	10	6678.3	4399.0	10	4398.9
5876.0	30	5876.0	4386.3	6	4385.4
5015.6	6	5015.9	4298.7	6	4298.5
4922.6	10	4922.3	4227.1	5	4226.89
4870.6	7	4870.4	4178.1	1	4179.5
4847.3	7	4848.7	3964.8	10	3964.0 H[2]
4805.6	9	4805.25	3948.2	10	3945.2 H
4713.4	9	4713.4	3913.2	4	3913.5 H
4559.4	2	4558.9	3888.5	10	3888.73 H
4520.9	3	4522.9	3819.4	10	3819.8 D
4471.5	10	4471.8	3732.5	5	3733.3
4437.1	1	4437.2	3705.4	6	3705.9 D
4428.1	10	4426.6			

[1] "A Treatise on Astronomical Spectroscopy," by Dr. J. Scheiner, translated by E. B. Frost, Boston, 1894.

[2] The wave-lengths to which the initials D and H are added are wave-lengths of lines photographically detected in the spectrum of the chromosphere by Deslandres (D) and Hale (H). Their photographs do not extend beyond wave-length 3630. Professor Lockyer (*Roy. Soc. Proc.*, **58**, 116, May 1895) has already pointed out fourteen coincidences between the wave-lengths of lines in terrestrial helium and in those observed in the chromosphere, the eclipse lines, and stellar spectra.

Minor Contributions and Notes.

NOTE ON A DIFFERENTIAL METHOD OF DETERMINING THE VELOCITY OF STARS IN THE LINE OF SIGHT.

The publication of M. Orbinsky's article[1] on a differential method of determining the velocity in the sight-line of stars whose spectra have been secured by an objective-prism, together with Professor Vogel's favorable comment on the method, justly arouses interest. None of the plans hitherto proposed for thus utilizing objective-prism plates have proved successful, and any new suggestions deserve attention.

An especial defect in the method of which M. Orbinsky writes lies in the fact that it requires the spectra of two different stars to be brought side by side upon the plate by successive exposures. This introduces serious danger of unequal flexure at the two different pointings of the telescope; and, still more, it fails to make available for the purpose in hand the great number of plates already secured by the Harvard College Observatory.

In a letter sent to Professor E. C. Pickering on May 29, 1893, I suggested a plan identical with that of M. Orbinsky, except that it utilizes all the spectra which, from the position of the stars, would naturally fall within the field of a plate. I quote from that letter: "I assume that the velocity of one star on the given plate has already been determined by the spectrographic method, and the velocities of the other stars on the plate are to be referred to it. For convenience, suppose that the velocity of the standard star (α) has been found to be zero. Let the perpendicular distance between the F line (or, better still, any line common to both spectra and as far toward the red as possible) in the star α and the F (or less refrangible) line of the star β, whose velocity is desired, be accurately measured on a dividing engine; similarly let the perpendicular distance between the K (or better, more refrangible) lines in the two spectra be measured. The difference between these distances $F\alpha - F\beta$ and $K\alpha - K\beta$ will measure the relative velocity of the two stars in the line of sight."

[1] *A. N.* **138**, 9–12.

As an example of the method I selected the stars δ and ε Orionis, which are near enough together to fall on the same plate, and whose velocities have been accurately determined at Potsdam. As the constants of the prisms were unknown to me, I was obliged to assume them to be the same as for Chance's flint glass. The fact was taken into account that the rays from one of the stars would be inclined by an angle θ to the principal plane of the prism, so that instead of the index of refraction n, the quantity $\sqrt{n^2 + (n^2 - 1)\tan^2\theta}$ must be used in obtaining the deviation. As a result I found that the displacement on one of the plates taken with four prisms should amount to about $0^{mm}.01$.

It is evident that the displacements of spectra near the edges of the plates might be masked by distortions, involving numerous corrections in the course of the computation, but the Harvard plates overlap to such an extent that the spectra very near the edges of a plate would seldom need to be used. The accuracy of this form of the differential method is not greater than in the form suggested by M. Orbinsky; the effects of distortion by the lens and prisms may be as serious as those of flexure in pointing at different stars, but the great advantage is gained that all the spectra sufficiently bright and not too far from the center of the plate, whose spectral types are comparable, can be measured on a single plate. As I stated in my letter to Professor Pickering, "Of course this method would not pretend to compete with the spectrographic method, but it seems to me that it might serve to give an idea of the direction and order of velocity of a great number of stars, and thus to sift out large velocities and interesting cases. It certainly would be one of the highest merits of any method that it makes available the great number of valuable plates which you have already obtained."

EDWIN B. FROST.

HANOVER, N. H.,
August 13, 1895.

NOTE ON THE DUPLICITY OF THE D_3 LINE.[1]

IN September 1884, while absent from the Observatory of Palermo, Sig. A. Mascari, my assistant, wrote me that he had observed the line D_3 double; on March 9, 1886, in observing a very bright prominence with rather a narrow slit I also saw the line D_3 double.

[1] From the *Astronomische Nachrichten*, No. 3305.

But as this line was then generally regarded as single, and by those who had observed it with instruments far more powerful than ours, while this line had not yet been observed double in any terrestrial body; and moreover since a duplication as well of the other principal bright lines of the chromosphere and likewise of all the dark lines of the photosphere, which were not too fine, was seen with the slit somewhat widened, I considered that the duplication of D_3 was not a phenomenon to be regarded as objective and characteristic of helium.

I referred to this phenomenon in *Comptes Rendus* No. 15 (April 12, 1886), and in the *Memorie degli Spettroscopisti Italiani*, Vol. XV, 1886. In the same year I showed the duplication of all the coarser solar lines, bright and dark, to several persons, including Professor H. Ebert, then in Palermo.

A. RICCÒ.

R. OSSERVATORIO DI CATANIA,
July 29, 1895.

NOTE ON EARLIER OBSERVATIONS OF ATMOSPHERIC ABSORPTION BANDS IN THE INFRA-RED SPECTRUM.

IN his second article on the emission of gases (*Wied. Ann.*, **51**, p. 5, 1894), Dr. Paschen expresses himself as being at a loss to know why Langley and others failed to find the atmospheric cold bands at about $\lambda 2^{\mu}.6$ and $4^{\mu}.2$ in the infra-red spectra of heated solids, while noting other absorption bands which, according to Paschen, are much less effective.

The apparent inconsistency is readily explained if it is noted, first, that in the great water-vapor band whose center is at $\lambda 6^{\mu}.6$ for hot emission, and at $\lambda 7^{\mu}.1$ for cold absorption, the *percentage* of absorption for rays of that wave-length is larger than the corresponding percentage for the combined water and carbon dioxide band at $\lambda 2^{\mu}.6$; while, in the second place, the early measures (at Allegheny) were largely made in spectra of solids near the boiling point of water, where the wave-length of the energy in the prismatic maximum nearly coincides with that of the great water-vapor absorption band at $\lambda 7^{\mu}.1$. Owing to the latter circumstance this band has an especially marked prominence, which is not so striking to the eye, when viewed in a high temperature curve, because the energy is there relatively feeble at the position of the greater band. Meanwhile the increasing energy of the shorter waves with rising temperature lends undue prominence to the

appearance of the smaller absorption bands in these regions of shorter wave-length.

While the great width of the water vapor band at $\lambda 7^{\mu}.1$ makes it less pronounced to the eye than one of the sharper notches of the spectral energy-curve, this same width, and the position of the region of absorption in the neighborhood of the maximum emission from bodies at ordinary terrestrial temperatures, make the "great band" at $\lambda 7^{\mu}.1$ by far the most important of the water-vapor bands. (See, for example, the curve of atmospheric transmission, *Am. Jour. of Sci.*, **38**, Dec. 1889, plate 10, where the successive cold bands, largely due to water-vapor, find their culmination in this great band at a rock-salt deviation of $38\frac{1}{2}°$. It may be noted that the bands less refrangible than the great band, and there exhibited on the prismatic scale would be much narrower and more symmetrical with the more refrangible series if they were represented on the normal scale.)

Dr. Paschen's allusion to the atmospheric absorption bands at $\lambda 2^{\mu}.6$ and $4^{\mu}.2$ as "much stronger" than the band at $\lambda 7^{\mu}.1$, is only true for high temperature curves, and, even then, only for the apparent importance as judged by the prominence of the inflection in the spectral energy curve, or by the diminution of the total energy for the sum of all wave-lengths; but since the proportion of the total energy struck out in a given absorption band varies with the temperature of the radiating body, it is fairer to describe the intensity of the band as a percentage of its own nearly homogeneous radiations. Judged by this standard, there can be no doubt that the atmospheric absorption band at $\lambda 7^{\mu}.1$ is the *great* water-vapor band as it is much the greatest gap in the spectrum for terrestrial radiations, and in fact Dr. Paschen's footnote (p. 23, *loc. cit.*) admits as much.

I have explained why the cold-bands of shorter wave-length are not conspicuous in the spectral energy-curve of a body at low temperature, where the absorbable energy of shorter wave-length is small. Actually, traces of these bands at shorter wave-lengths were found as early as 1885 by Dr. Langley and myself while observing some of these low temperature spectra, but owing to the necessity at that time for the use of a wide bolometer, and a galvanometer highly astaticized for the detection of heat in the spectrum of a blackened copper radiator at 100° C., seen under a small angle at a distance of 100 meters, and owing further to the shifting of the apparent position of a cold band on the rapidly descending branch of a spectral energy curve, towards the side of lesser

heat, exact positions could not be obtained; and even the existence of such absorption in so short an air-column was not then as certain as could be wished.

Examples of some of these results have been published in the memoir on "The Temperature of the Moon" (*National Acad. of Sci.*, 4, Part 2, p. 186, Washington, 1889).

We may conclude that while the absorption band at λ 2$^{\mu}$.6 is the principal water-vapor band at high temperatures, the great band ($\lambda = 7^{\mu}.1$) is chief at low temperatures, and probably the transfer of the title "principal band" might go on indefinitely, if dissociation did not fix a limit of temperature above which it is impossible for water to exist.

F. W. VERY.

FRIEDRICH WILHELM GUSTAVE SPÖRER.[1]

ON the 7th of last July Professor Dr. Friedrich Wilhelm Gustave Spörer, until recently First Observer at the Astrophysical Observatory at Potsdam, died suddenly from heart failure.

Dr. Spörer was born in Berlin on October 23, 1822, and after attending the Friedrich-Wilhelm Gymnasium, devoted himself during the years from 1840 to 1843 especially to mathematical and astronomical studies at the University of Berlin. On December 14, 1843, he took his degree with a thesis on the Comet of 1723, dedicated to his instructors Encke and Dove. During the succeeding years he busied himself with astronomical computation, under Encke's direction, at the Observatory at Berlin, and after passing the *Staats-Examen* he went in 1846 to the gymnasium in Bromberg, as instructor in mathematics and science; from there he went in 1847 to Prenzlau, and in 1849 to Anclam, where he was engaged for twenty-five years as instructor, and finally as prorector of the gymnasium there.

His preference for astronomy had led him to devote his leisure hours since 1860 to observations of Sun-spots. His restless assiduity and great perseverance are clearly shown by his success in carrying on investigations of much scientific value in the field of Sun-spot statistics, which soon made his name known in the scientific world, although he possessed only an inferior instrumental equipment, consisting of a small telescope provided with a ring micrometer.

Professor Shellbach, instructor of the then Crown Prince, afterward

[1] From the *Astronomische Nachrichten*, No. 3303.

the Emperor Friedrich, called the attention of his royal pupil to Spörer, and the Crown Prince in 1868 aided Spörer's endeavors by providing him with a refractor of five inches aperture, equipped with clockwork, with which he could now carry on his observations according to the well-known method of projection on a larger scale.

The results of his investigations carried on at Anclam have appeared in numerous articles in the *Astronomische Nachrichten*, and in two large memoirs which appeared in 1874 and 1876 as publications of the Astronomische Gesellschaft. The especial merit of these works lies in the careful determination of the law of the Sun's rotation, and also in the close corroboration of the law already formulated empirically by Carrington, which sets forth the diminution in rapidity of Sun-spot rotation from the equator towards the poles.

In 1868 Spörer, with Professor Tietjen and Dr. Engelmann took part in the astronomical expedition which was sent to the East Indies by Germany to observe the total eclipse of the Sun.

In 1874 Spörer received a call as observer to the Astrophysical Observatory at Potsdam, plans for which were then under way. He removed in this same year to Potsdam and carried on his Sun-spot observations with his instrument installed on the tower of the Soldiers' Orphan Asylum in Potsdam.

His industry continued in the larger circle of activity which opened to him at the Observatory in Potsdam and his work was now largely devoted to the field of Sun-spot statistics, to which he devoted himself with unwearying attention and the same zeal as in Anclam.

The four comprehensive memoirs compiled by him, which appeared in the publications of the Astrophysical Observatory, contain a rich amount of observation-material which has a lasting value in the study of the proper motion of Sun-spots.

In 1882 Spörer was appointed First Observer. This position he occupied until October 1, 1894, when in consideration of his advancing years he was released from service, and entered into well-earned retirement, which unfortunately he was not long permitted to enjoy.

Spörer's life was rich in good fortune and external prosperity, and thanks to his unusual good health he remained to the day of his death free from the infirmities of age. While on a journey to visit his children, without the slightest previous suggestion of sickness, he passed quietly and painlessly away. H. C. V.

Reviews.

Bemerkung zu der Abhandlung über Lichtemission (*Wied. Ann.* **53**, 832), G. Jaumann. *Wied. Ann.* **54**, 178.

In this note the author states that the conclusions published in his previous paper (translated in the present number of The Astrophysical Journal) have been in part anticipated by Lommel (*Wied. Ann.* **3**, 251, 1878), whose explanation of the broadening of spectral lines as a result of damped vibrations seems to have been generally overlooked. Lommel did not, however, extend his theory to the explanation of banded spectra. It is pointed out that Lommel's investigation of the distribution of intensity in the widened line is erroneous, since he resolves the damped vibration into a *continuum* of sine vibrations with all oscillation-frequencies between $+\infty$ and $-\infty$, in which therefore each color is contained *twice*. The maximum does not fall at the place which corresponds to the period of the damped vibration, as it would according to this process, but at a place somewhat nearer that of the undamped vibration. Ebert has, in fact, found that with increased density of the luminous vapor all widened spectral lines are displaced slightly toward the red. The method which he employed (that of interference with large difference of path) is particularly suited to the determination of such small displacements and hence of the constant of damping.

The paper by Lommel which is referred to by Professor Jaumann contains a development of the principle of damped vibrations and its application to the phenomena of fluorescence. Lommel remarks that the assumption of damping represents a condition more common in nature than free oscillation, as almost all motion takes place under resistance.

The usual method of treatment in which the resistance is not considered is a special case of the preceding. The paragraph in which Lommel sums up his conclusions with regard to the widening of spectral lines (omitting a few words referring to the formulæ of development) may be rendered as follows:

The light emitted by an atom which vibrates against resistance is, therefore, not homogeneous but is spread out by a prism into a continuous spectrum, extending on both sides of the place corresponding to the principal vibration-frequency to a distance which increases with the coefficient of resistance. J. E. K.

Recent Publications.

A LIST of the titles of recent publications on astrophysical and allied subjects will be printed in each number of THE ASTROPHYSICAL JOURNAL. In order that these bibliographies may be as complete as possible, authors are requested to send copies of their papers to both Editors.

For convenience of reference, the titles are classified in thirteen sections.

1. THE SUN.

BROWN, E. Growth and Decay of Sun-spots. Jour. B. A. A. **5**, 460–461, 1895.

COIT, J. R. A Solar Prominence. A. J. No. 350, 112, 1895.

CORDER, HENRY. Growth and Decay of Sun-spots. Jour. B. A. A. **5**, 458–459, 1895.

DOOLITTLE, ERIC. Some Interesting Results of Helmholtz's Theory of Solar Contraction. Pop. Ast. **3**, 21–24, 1895.

HALE, GEORGE E. Preliminary Note on the D_3 line in the Spectrum of the Chromosphere. A. N. **138**, 227–230, 1895.

HUGGINS, W. On the Duplicity of the Solar Line D_3. A. N. **138**, 229–230, 1895.

LOCKYER, J NORMAN. The Sun's Place in Nature. VIII. Nat. **52**, 253–255, IX. 327–329, X. 422–425, 1895.

MASCARI, A. Sulla frequenza delle macchie solari osservate nel Regio Osservatorio di Catanianel-l'anno 1895. Mem. Spettr. Ital., **24**, 97–102, 1895.

OSTEN, HANS. Der grosse Sonnenfleck. Sir. **23**, 185–186, 1895.

QUIMBY, A. W. Sun-spot Observations. A. J. No. 350, **15**, 107, 1895.

RICCÒ, A. Il Sole. Università di Catania, 1895, 24. pp.

RICCÒ, A. Sulla duplicità della riga solare D_3. A. N. **138**, 287–288, 1895.

SAMPSON, R. A. On the Rotation and Mechanical State of the Sun. Mem. R. A. S. **51**, 123–183, 1895.

SCHAEBERLE, J. M. Report on the Total Eclipse of the Sun observed at Mina Bronces, Chile, on April 16, 1893. Contributions from the Lick Observatory, No. 4.

TACCHINI, P. Protuberanze solari osservate al Regio Osservatorio del Collegio Romano nel 2° trimestre del 1895. Mem. Spettr. Ital. **24,** 107–108, 1895.

TACCHINI, P. Sulla distribuzione in latitudine dei fenomeni solari osservati al Regio Osservatorio del Collegio Romano nel 2° trimestre del 1895. Mem. Spettr. Ital. **24,** 110–116, 1895.

TACCHINI, P. Macchie e facole solari osservate al Regio Osservatorio del Collegio Romano durante il 2° trimestre del 1895. Mem. Spettr. Ital. **24,** 103–106, 1895.

TODD, D. P. The Sun. Science, **2** (Ser. 2), 29–39, 1895.

TOWNSEND, J. S. List of Groups 1894–1895, showing whether larger near the East or West Limb of the Sun. Jour. B. A. A. **5,** 468, 1895.

WILSON, W. E. The thermal radiation from Sun-spots. M. N. **55,** 457–462, 1895.

WOLFER, A. Ueber das Thätigkeitsgebiet der grossen Sonnenfleckengruppe vom Februar 1892. Wolf's Astron. Mitteilungen No. 85. V. J. S. Naturfor. Gesell. Zürich, **40,** 139–186, 1895.

WONASZEK, A. A. Zählungen von Sonnenflecken. A. N. **138,** 257–260, 1895.

3. STARS AND STELLAR PHOTOMETRY.

CAMPBELL, W. W. Observations of Nova (5533 R) Normae. A. J. No. 349, **15,** 100, 1895.

CAMPBELL, W. W. Observations of Nova (7787 Q) Cygni. A. J. No. 349, **15,** 100, 1895.

EASTON, C. On the Distance of the Stars in the Milky Way. Knowl. **18,** 179–182, 1895.

FLANERY, D. Fluctuations of Mira Ceti. Knowl. **18,** 182–183, 1895.

MARKWICK, E. E. Note on the variable star T Centauri, Cord. G. C. 18609. A. N. **138,** 213–214, 1895.

MINCHIN, GEORGE M. The Electrical Measurement of Starlight. Nat. **52,** 246–248, 1895.

MINCHIN, G. M. The Electrical Measurement of Starlight. Proc. R. S. **58,** 142–155, 1895.

PARKHURST, HENRY M. On the Light-Curve of 103 T Andromedæ. A. J. No. 352, **15,** 135–136, 1895.

PARKHURST, HENRY M. Notes on Variable Stars, No. 9. A. J. No. 350, **15,** 105–106, 1895.

PARKHURST, J. A. Maxima and Minima of Long-Period Variables. A. J. No. 349, **15,** 99–100, 1895.

PAUL, H. M. Observations of X Hydrae. A. J. No. 349, **15,** 103, 1895.

PAUL, H. M. Confirmations of Variability. A. J. No. 352, **15**, 132–133, 1895.

ROBERTS, ALEX. WM. New Variable near S Velorum. A. J. No. 352, **15**, 134–135, 1895.

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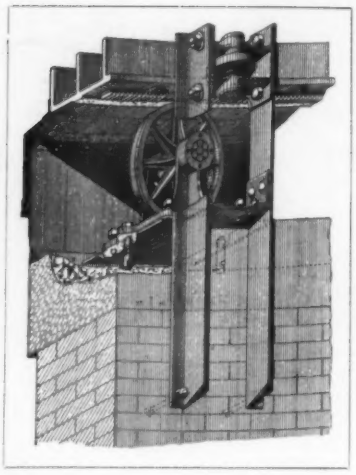

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